Smart Innovation, Systems and Technologies 66

Amaresh Chakrabarti
Debkumar Chakrabarti *Editors*

Research into Design for Communities, Volume 2

Proceedings of ICoRD 2017

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Preface

Design is ubiquitous; it pervades all spheres of life, and has been around ever since life has been engaged in purposefully changing the world around it. While some designs have transcended time, most designs are in a perpetual process of being evolved. Research into design and the emergence of a research community in this area have been relatively new, and its development has been influenced by the multiple facets of design (human, artefact, process, organisation, ecology, micro- and macro-economy by which design is shaped and which it shapes in turn) and the associated diversification of the community into those focusing on various aspects of these facets, in various applications. Design is complex, balancing the needs of multiple stakeholders, and requiring a multitude of areas of knowledge to be utilised, with resources spread across space and time.

The collection of papers in two book volumes constitutes the Proceedings of the Sixth International Conference on Research into Design (ICoRD'17) held at the Indian Institute of Technology Guwahati, India during 9–11 January 2017. ICoRD'17 is the sixth in a series of biennial conferences held in India to bring together the international community from diverse areas of design practice, teaching and research. The goals are to share cutting-edge research about design among its stakeholders; to aid the ongoing process of developing a collective vision through emerging research challenges and questions; and to provide a platform for interaction, collaboration and development of the community in order for it to address the global and local challenges by forming and realising the collective vision. The conference is intended for all stakeholders of design, and in particular, for its practitioners, researchers, teachers and students.

348 abstracts were submitted to ICoRD'17 and selected for full paper submission. 223 full papers were submitted, which were reviewed by experts from the ICoRD'17 International Programme Committee comprising 241 members from over 151 institutions or organisations from 32 countries spanning five continents. Finally, 177 full papers, authored by 356 researchers (356 unique authors, actually 502 author entries in 177 papers) from 117 institutions and organisations from 19 countries spanning six continents, were selected for presentation at the conference and for publication as chapters in this book. ICoRD has steadily grown over

the last five editions, from a humble beginning in 2006 with 30 papers and 60 participants, through 75 papers and 100 participants in ICoRD'09, 100 papers and 150 participants in ICoRD'11, 114 papers and 170 participants in ICoRD'13, to 118 papers and 200 participants in ICoRD'15.

ICoRD'17 had 129 podium papers and 48 papers with brief podium presentations, followed by poster display and discussion. It had keynotes from prominent researchers and practitioners from around the world such as Tetsuo Tomiyama from Cranfield University, UK, Jinan KB from Reimagining School, India, Cees de Bont from Hong Kong Polytechnic University, Hong Kong, Nitin Gupta from Sickle Innovations, India, Monica Bordegoni from Politecnico di Milano, Italy, Pradeep Yammiyavar, IIT Guwahati, India and Arun Garg, University of Wisconsin-Milwaukee, USA. It had one panel discussion on 'Practice of Design' and four workshops on decision-making in design, emotional engineering, publishing papers and Asia design. From 2015, ICoRD started giving ICON3 awards (acronym for ICoRD Outstanding Contribution to desigN scieNce and educatioN) to outstanding contributors to design education and research. Professor Sudhakar Nadkarni from Welingkar Institute of Management, India and Professor John Gero from George Mason University, USA were selected as ICON3 awardees for 2015, for their outstanding contributions to design education and design research, respectively. Professors Tetsuo Tomiyama of Cranfield University, UK and Professor Cees de Bont from Hong Kong Polytechnic University, Hong Kong have been selected as the ICON3 awardees for 2017.

The chapters in the two book volumes together cover all three major areas of products and processes: functionality, form and human factors. The spectrum of topics range from those focusing on early stages such as creativity and synthesis, through those that are primarily considered in later stages of the product life cycle, such as safety, reliability or manufacturability, to those that are relevant across the whole product life cycle, such as collaboration, communication, design management, knowledge management, cost, environment and product life cycle management. Issues of delivery of research into design, in terms of its two major arms such as design education and practice, are both highlighted in the chapters of the book volumes. Foundational topics such as the nature of design theory and research methodology are also major areas of focus. It is particularly encouraging to see in the chapters the variety of areas of application of research into design—aerospace, health care, automotive and so on.

The theme of ICoRD'17 has been 'Design for Communities'. While design traditionally focused on the development of products for the individual, the emerging consensus on working towards a more sustainable world demands greater attention to designing for and with communities, so as to promote their sustenance and harmony—within each community and across communities. ICoRD'17 has been hosted at the foothills of the Himalayas in the north-east of India, which is home to myriad linguistic and cultural communities with their own traditions, heritage and aspirations. It was only appropriate that the theme for ICoRD'17 aligned with this ambiance.

This volume, ‘ICoRD’17—Design for Communities, Volume 2’, focuses on the topics of creativity, sustainability, collaboration and communication, lexicon, taxonomy, ontology, aesthetics, and training and education.

On behalf of the steering committee, advisory committee, organising committee and co-chairs, we thank all the authors, delegates, institutions and organisations that participated in the conference. We also thank members of the International Programme Committee for their support in reviewing the papers for ICoRD’17, which is essential for maintaining the quality of the conference, and for their support in putting this book together.

We are thankful to the Design Society and Design Research Society for their kind endorsement of ICoRD’17. We thank Indian Institute of Technology (IIT) Guwahati and its Department of Design, and Indian Institute of Science (IISc), Bangalore and its Centre for Product Design and Manufacturing, for their support of this event. We also wish to place on record and acknowledge the enormous support provided by Ms. Kumari M.C., Mr. Ranjan B.S.C. and Ms. Nishath Salma of IISc in managing the review process, and in preparation of the conference programme and this book, and the large and dedicated group of student volunteers of IIT Guwahati and IISc Bangalore in the organisation of the conference. A special thanks to Dr. Prasad Bokil of IIT Guwahati for his relentless, day-to-day organisational support and leadership to make ICoRD’17 a success. Finally, we thank Springer, especially senior editor Swati Meherishi and editorial assistant Aparajita Singh, for the wonderful support extended in the publication of this book and in sponsoring books and book coupons for ICoRD’17 distinguished paper awards and ICON3 awards.

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About the Conference

Design is ubiquitous; it pervades all spheres of life, and has been around as long as life has taken up the task of purposefully changing the world around it. Research into design and the emergence of a research community in this area have been relatively new. Its development has been influenced by the multiple facets of design (human, artefact, process, organisation, the micro- and macro-economy and the ecology by which design is shaped) and the associated diversification of the community depending on the facets of focus or that of their applications. Design is complex, balancing the needs of multiple stakeholders, and requiring a multitude of areas of knowledge to be utilised, and resources spread across space and time.

ICoRD'17 is the sixth in a series of conferences intended to be held every two years in India to bring together the international community from diverse areas of design practice, education and research. It aims to showcase cutting-edge research about design to the stakeholders; aids the ongoing process of developing and extending the collective vision through emerging research challenges and questions; and provides a platform for interaction, collaboration and development of the community in order for it to take up the challenges to realise the vision. The conference is intended for all stakeholders of design, and in particular, for its practitioners, researchers, pupils and educators.

The theme of ICoRD'17 is 'Design for Communities'. While design traditionally focused on the development of products for the individual, the emerging consensus on working towards a more sustainable world demands greater attention to designing for and with communities, so as to promote their sustenance and harmony —within each community and across communities. ICoRD'17 is hosted at the foothills of the Himalayas in the north-east of India, which is home to myriad linguistic and cultural communities with their own traditions, heritage and aspiration. It is only appropriate that the theme for ICoRD'17 aligns with this ambiance. The conference contained the following:

- Invited/keynote presentations from eminent international experts and practitioners;
- Panel discussion and presentations of refereed papers as podium and poster presentations;
- Presentation of ICoNNN awards and keynotes;
- Networking sessions for young researchers;
- Workshops on dedicated topics.

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Part III Design Lexicon, Taxonomy, Ontology

Part IV Design Aesthetics, Semiotics, Semantics

About the Editors

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Debkumar Chakrabarti is a professor with higher administrative grade scale (former head of the department) at Department of Design, Indian Institute of Technology Guwahati, India, since 2008. Presently, he is also heading Central Institute of Technology Kokrajhar, Assam, India, as director (officiating). He has 35 years of teaching (UG, PG and Ph.D. levels) and research experience with various capacities with special interest in the domain of ergonomics/human factors and industrial design. Six Ph.D. students have completed their Ph.D. under his able guidance and many others are continuing. Prof. Chakrabarti holds M.Sc. in human physiology with specialisation in ergonomics and work physiology from Presidency College, Calcutta University and Ph.D. in science (physiology, in the area of design ergonomics) from University College of Science, Technology and Agriculture, Calcutta University. He has been dealing with broad spectrum of ergonomics teaching and research which encompass ergonomics and human factors fundamentals; usability and human compatibility factors; design ergonomics and human–product–environment interface system; cognitive perception and interaction ergonomics; occupational health and safety; and participatory ergonomics and training. He has around 164 publications in various journals, conference proceedings, technical reports and books. He had delivered an online 40 video lecture series and ten experiments on physical ergonomics—anthropometric techniques under virtual laboratory scheme of NPTEL, MHRD, Government of India. He has carried out his responsibility as examiner and invited speaker and member in many committees with varied administrative responsibility for many organisations from time to time till date. Few of these professional bodies include Bureau of Indian Standards (BIS, ergonomics committee member), Department of Science and Technology (TIDE member) and Indian Society of Ergonomics (vice-president, Indian society of Ergonomics). He also served as guest faculty with varied durations for many institutes.

Part I
Eco-design, Sustainable Manufacturing, Design for Sustainability

Supporting Environmentally-Benign Design: Environmental Impact Estimation and Uncertainty Categories with Respect to Life Cycle Assessment in Conceptual Design

Shakuntala Acharya and Amaresh Chakrabarti

Abstract The goal of the conceptual design stage is to specify the solution principle, i.e., the concept; to design an environmentally-benign product, it is imperative that the most environmentally-benign concept is selected. However this selection can occur only upon evaluation of alternative solution-variants with respect to their potential environmental impacts. Life Cycle Assessment (LCA) is the most widely used approach to estimate environmental impacts of a product. However, at these early stages of design, information available on the lifecycle of the concepts is incomplete, subjecting LCA results to various sources of uncertainty. The environmental impact of a concept can thus be better gauged only upon considering the uncertainty in this estimation of impact. This paper proposes an uncertainty category called 'solution-variant definition', to be used in conceptual design, as a precursor to the more established uncertainty category called 'structure definition' for use at the embodiment design stage. It also elucidates that each sub-category of 'solution-variant definition' can be described using the 'outcomes' of the SAPPhIRE Model of Causality, and exhibits the same flow of causality. It is proposed that considering this uncertainty, along with other, more established uncertainties in Environmental Impact estimation, would support consideration of uncertainties in Conceptual design as opposed to only later in embodiment stages. This paper presents as to how decisions taken earlier could have a profound impact on the product with respect to its environmental-benignity.

Keywords Eco-design · Design for sustainability · Design creativity · Synthesis · Evaluation and optimisation · Sapphire model of causality · Environmental impact assessment · Uncertainty

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1 Introduction

It is not the product but its entire lifecycle that determines the environmental impact of the product and its associated processes [1–3]. Vezzoli and Manzini [4] coined the term ‘Life Cycle Design’ to encourage regard of “every possible environmental implication connected with every stage of a project’s life cycle” to reduce the environmental impact. With respect to industrial production, Ayres [5] stressed that “impacts should be viewed on an integrated or life-cycle basis, rather than in isolation” and that the circulation of materials and waste production through the society must be viewed holistically. The lifecycle of a product is largely determined during the design stages, where early stages, such as conceptual design, play a crucial role [2, 6].

Pahl and Beitz [7] described the conceptual design process as a path that specifies the solution principle. They elaborated the solution path with certain steps of which ‘searching for appropriate working principles’ and ‘combining these into a working structure’ culminated into development of solution-variants. And further stated that a successful solution was most often found to be developed from “the choice of the most appropriate principles than from exaggerated concentration on technical details”. Thereby, not only stressing on the influential character of ‘principles’ upon solutions but also on the importance of design decisions at conceptual stage upon success of the solution.

An environmentally-benign design is that which causes little or no harm to the natural environment and this is achieved by supporting designers in making decisions that reduce the environmental footprint of a product [8–11].

However, unlike the embodiment design stage where availability of product information is higher due to a greater number of more detailed decisions made, “flexibility” is high at the conceptual stage [12, 13]. Design decisions during this stage require adequately accurate estimates to select the more environmentally-benign concepts amongst the solution-variants considered. Thus, uncertainty, defined as the “accuracy of the estimation rather than the probability of finding the correct estimate” [12] must be accounted for in calculating the environmental impact estimation of a solution-variant.

The Objectives of this paper are as follows;

(i) To review the appropriateness of SAPPhIRE Model of Causality to capture the outcomes of conceptual design stage at various levels of abstraction of a concept, and the propagation of impact across these. This is addressed using Literature Review.

(ii) To elucidate through empirical study the evolution of a product’s ‘structure’ at the embodiment stage from its precursor at the conceptual stage—the solution—described as a ‘set’ of outcomes at different levels of abstraction from which eventually the structure arises. This paper proposes the uncertainty category of ‘solution definition’, with respect to LCA, for conceptual design, and formulates its sub categories from the successive sub-categories of the 'structure definition' uncertainty category used at the embodiment design stage. This is addressed using Literature Review and Descriptive Study I [14].

(iii) To establish, through empirical study, that the availability of environmental impact values with uncertainty, for a solution-variant at conceptual design, improves design decision-making by prompting the selection of the most environmentally-benign solution as concept. This paper presents a comparison of design decisions taken at the embodiment stage with decision choices available at the conceptual stage. This is also addressed using DS-I.

2 Literature Review

The goal of conceptual design is the "specification of a Principle Solution", i.e., concept [7]. To do this, multiple variants of the solution are prescribed to be generated, from which the best one is (to be) selected after multiple evaluations and modifications. However, Cross [15] observes that design problems can have many different levels of generality or detail; a concept is made of ideas that are at multiple levels of abstraction [6]. This poses a challenge for evaluating environmental impacts of solution-variants, as each solution-variant comprises sub-solutions at many levels of abstraction or detail.

2.1 Solution Description and Environmental Impact Propagation in Conceptual Design Stage

Tools for Eco-design during conceptual stage, such as 'Eco-efficiency parametric screening (Eco-Pas) proposed by Duflou et al. [16], as well as 'Function Impact Matrix' (FIM) proposed by Zhao et al. [17], identify 'Functional Requirements' as discrete building blocks for mechanical systems and limits their use to designs that have precedence and prior art, and/or catalogued knowledge of specifications. However, this approach restricts the conceptual design process to specific 'functional requirements' and their known parametric-design solutions. It is understood that requirements and solutions co-evolve particularly during the conceptual stage, and that generation/synthesis of 'new' designs is the key motivation conceptualisation and occurs at various levels of abstraction, due to scarce knowledge and high uncertainty. Hence, this method affords new product design which is the key outcome sought in conceptual design stage.

SAPPhIRE is a model of *outcomes*, where an outcome is defined as a property of an entity (e.g. a design) at an abstraction level and, therefore, is a type of product knowledge. It captures the multiple levels of abstraction that a design evolves through during design, which, elaborated at each level, provides a particular description of the design as an outcome [6]. It is also a model of causality, i.e., it makes explicit use of effects in describing the causality of entities, where outcomes are causally related to one another across the levels of abstraction to explain the functioning of the entity.

It consists of the following constructs [6]: *parts*, *physical phenomenon*, *state* (change), *physical effect*, *organ*, *input*, and *action*. The relationships between these constructs are as follows: parts (P) of an entity and its surroundings create organs (R), which are the structural requirements for a physical effect (E). A physical effect is activated by various inputs (I) on the organs and creates a physical phenomenon (Ph), thereby changing the state (S) of the system. The changes of state are interpreted as actions (A), as new inputs, or as changes that create or activate parts.

Based on this, Acharya and Chakrabarti [8] found that the SAPPhIRE model was appropriate for describing solutions as a set of verifiable and quantifiable design outcomes at different levels of abstraction. It was also reported that the environmental impact of outcomes at different levels of abstraction propagated along the causal flow of the model. Thus, they proposed that the environmental impact of an outcome at a certain level of abstraction could be represented as "a collation of Environmental Impact information of all the outcomes at each of its subsequent lower levels".

2.2 Environmental Impact Estimation in Conceptual Design and Relevance of Uncertainty Analysis

Sigel et al. [18] noted that a large amount of knowledge is needed as a "solid foundation for decision-making" to develop 'good' solutions that address environmental problems . Environmentally-benign design is achieved by selecting the most environmentally-benign solution-variant, i.e., the solution-variant with the least environmental impact, as the solution-principle to be embodied into a 'good' product. The intent of this research is to support designers in making such design decisions by providing an estimate of the Environmental Impact (EI) of a solution at the conceptual stage.

Life Cycle Assessment (LCA) is a "technique for estimating the environmental aspects and potential long-term impacts of the whole life-cycle of products or service", as defined by ISO 14040 [4]. It is the most widely used method for estimating the environmental impact of a product. However, at early stages of design, information about the product-concept and its apparent life cycle is at best incomplete, subjecting LCA results to various sources of uncertainty. Based on their literature review, Kota and Chakrabarti [12] concluded that "uncertainty exists in LCA because of data inaccuracy, data gaps, model uncertainties, choices, spatial and temporal variability, variability between sources, etc."; they summarise these as 'Data Quality' uncertainties and 'Methodological (choices)' uncertainties. In addition to these, they also found that there are other uncertainties arising from design processes, such as Product-structure uncertainties and Life-cycle phase uncertainties, which are typically not accounted for in the earlier literature [12]. In order to estimate the potential environmental impact of a product, the uncertainties prevalent in its structure pertaining to its different life cycle phases must also be considered, and must be supported by relevant data and suitable methodology to integrate data. This is further discussed in the following section.

Thus, the true nature and potency of the environmental impact of a concept can be gauged only upon considering the uncertainty in the estimation of environmental impact, which is the focus of this paper. This is supported by Benetto and Dujet [19] according to whom there is need for "uncertainty modelling" to build decision support to efficiently interpret the LCA assessment data and results.

2.3 Uncertainty in Conceptual Design: Categorisation and Definition

Kota and Chakrabarti [12] categorised uncertainty in information with respect to LCA in design, and observed that uncertainty is propagated hierarchically. The uncertainty categories in embodiment design are;

– Uncertainty in Methodological Choices
– Uncertainty in Data Quality
– Uncertainty in Life-cycle Definition
– Uncertainty in Structure Definition

They stress that, "if LCA is used during earlier stages of design", reducible uncertainties like those associated with product structure and lifecycle phase, along with data and methodological uncertainty, must be considered [12]. However, in the conceptual design stage, a potential concept or solution-principle of a product does not have a clear, physical structure. Solution-variants exist as abstract descriptions of a structure-to-be, but can be described, as discussed above, as a 'set' of SAPPhIRE outcomes at different levels of abstraction. These abstract descriptions of a solution are a major source of uncertainty in conceptual design, which requires to be assessed.

Wood [20] differentiated the types of uncertainty prevalent in preliminary engineering design as—imprecision, stochastic uncertainty and probabilistic uncertainty. He defined imprecision as "uncertainty in choosing among alternatives in the description of design elements". He further stressed the necessity to formalise and quantify imprecision in design descriptions of possible solutions for carrying out design decisions based on available information and elementary principles of engineering. He further clarified that by 'imprecision' he referred to the "approximate or incomplete descriptions which have all the functions but lack the details" [21].

The key contribution of this paper is to elucidate ‘solution definition’ as an uncertainty category for LCA, so that this can used, along with other, more established categories of uncertainty, during conceptual design.

3 ‘Solution Definition’ in Conceptual Design as Evolutionary Precursor to ‘Structure Definition’ in Embodiment Design

3.1 Literature Review: Structure-Definition in Embodiment Design

Kota and Chakrabarti [12] proposed ‘Structure-definition’ as one of the categories of uncertainty in information with respect to LCA in design. The structure of a product broadly consists of parts and their relations or interfaces, each having some features. The hierarchal organisation of these parts and relations give rise to sub-assemblies and assemblies. The information available pertaining to each of these components of a product’s structure is high during the embodiment design stage, which “allows the categorisation of uncertainties based on decisions made”.

Uncertainty in ‘Structure-definition’ has five sub-categories, as given below:

(i) Uncertainty in the definition of assemblies, i.e., the collection of assemblies, sub-assemblies, parts, and interfaces among these in the particular assembly of the product: “all, some, or none”.
(ii) Uncertainty in definition of sub-assemblies, i.e., the collection of parts and interfaces in each sub-assembly of the product: “all, some, or none”.
(iii) Uncertainty in definition of interfaces, i.e., the connection between one or more features of one part and one or more features of another part in the product: “all, some, or none”.
(iv) Uncertainty in definition of parts, i.e., the smallest physical element in the product, not in size but in that it cannot be divided further into parts and interfaces: “all, some, or none”.
(v) Uncertainty in definition of features, i.e., the geometrical forms in a part: “all, some, or none”.

These sub-categories were developed from standard categories of description from computer-aided design (CAD) models. In an embodiment of a solution, each of these sub-categories of structure-definition can be identified. These play a crucial role in design-decisions by identifying the lifecycle processes associated with the product. For example, parts determine material choices, and hence is related to the material-phase of the life cycle; interfaces are associated with the manufacturing phase of the life cycle. Thus, as information available increases, the amount of uncertainty decreases.

3.2 Descriptive Study: Mapping 'Structure Defintion' to 'Solution Defintion'

Hubka and Eder [22] described designing as an act of "thinking ahead and describing a structure, which appears as (potential) carrier of the desired characteristics (properties, particularly the functions)". According to Acharya and Chakrabarti [8], at the conceptual design stage, since information available is low, it is not only difficult but inappropriate to associate a structure from a given function; They therefore proposed the use of SAPPhIRE outcomes as a representation for a solution-variant during conceptual design, where a solution-variant is described as a 'set' of outcomes at different levels of abstraction. However, the configuration of these outcomes, which would eventually give rise to a product structure, were not specified. This description of a solution-variant has been termed here as 'solution-definition', which is proposed as an evolutionary precursor to the 'structure definition' used in embodiment design; not all aspects of the solution, unlike that of a product-structure, are physical or manifested, but are abstract and vague.

Therefore, we hypothesise the following: *the specification of a construction or layout, i.e., the 'structure definition' at the embodiment design stage, can be mapped back to the specification of the solution-principle or concept, i.e., 'solution definition', at the conceptual design stage*.

3.2.1 Analysis of Design Sketches

To test the above hypothesis and to establish the representation of 'solution-definition' of a solution-variant, design sessions (from archives of protocols) were analysed across the two stages of design, namely conceptual stage and embodiment stage, with respect to their evolutionary correspondence.

Designs at the conceptual and embodiment stages for a given design problem 'design a multi-use furniture' was analysed; for detailed descriptions of this problem and associated designs, see Ranjan et al. [23]

- The design descriptions at the embodiment stage for every 'structure-definition' sub-category was noted, and
- Corresponding precursor description from the conceptual design stage was identified.

From these, categories of uncertainty for a 'solution definition' in conceptual design could be defined (Fig. 1).

3.2.2 Findings from Design Analysis

From the above design analysis, the description of a solution (i.e., concept) was found to be specifiable by the outcomes of SAPPhIRE and/or their configurations.

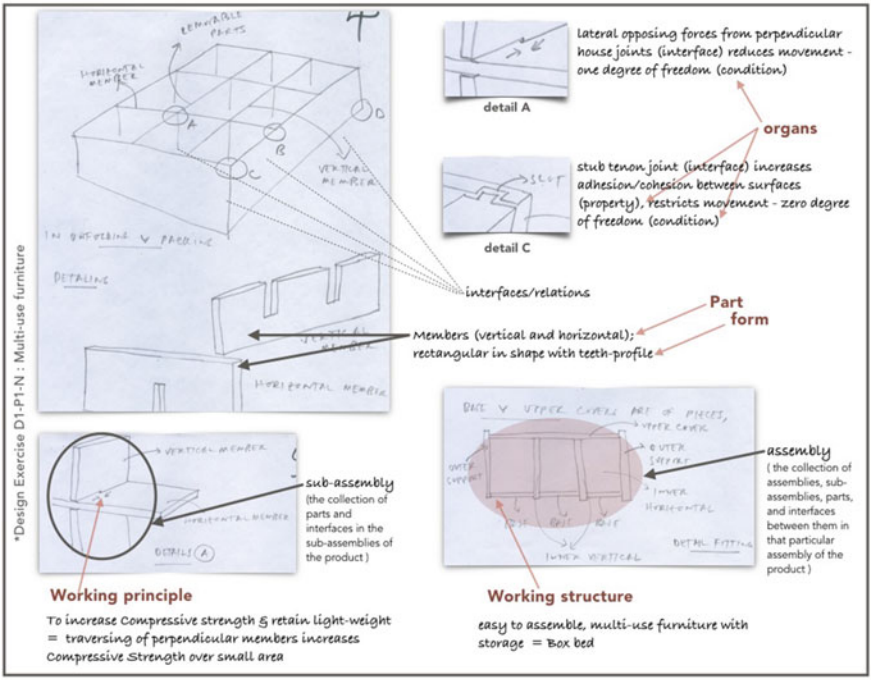

Fig. 1 Analysis of uncertainty categories correspondence from embodiment to conceptual stage of design

It was observed that at the lower levels of detail, there was a one-to-one mapping of structure (from embodiment design) to outcome (in conceptual design), as given below;

- *Parts* in embodiment design [12] evolved from *parts* in conceptual design that lacked detail;
- *Features* in embodiment design [12] evolved from *forms* in the conceptual stage, which were entities with rudimentary geometry that designers sketched free-hand and which lacked dimensions;
- *Relations* or *Interfaces* in embodiment design [12] evolved from *organs* in the conceptual stage, which specified the properties and conditions required for the final product.

However, at the higher levels of detail and complexity of a structure, such as assembly and sub-assemblies, the precursor at the conceptual stage was found to be a higher level outcome, or a configuration of outcomes, of SAPPhIRE, follows:

- A *sub-assembly* in embodiment design evolved from a "combination of physical effects with geometric and material characteristics (working surfaces, working motions and materials)" that allowed "the principle of the solution to emerge" [7] at the conceptual stage. This may be defined as Working Principle and corresponds to *phenomenon* (Ph) outcome of SAPPhIRE. A phenomenon in turn is the result of an *effect* (E) caused by *organs* (R) and *inputs* (I).

– An *assembly* in embodiment design evolved from a "combination of several working principles" resulting "in the working structure of a solution" [7] at the conceptual stage; which may be defined as Working Structure and corresponds to a number of *phenomenon* (Ph) or *state change* (S) outcomes of SAPPhIRE.

3.2.3 Conclusions from the Design Analysis

The main conclusion from the design analysis above is the following. The 'structure definition' of an embodiment of a product, comprising Assembly, Sub-assemblies, Relations and interfaces, Parts and Features, evolves from its 'solution definition' comprising corresponding categories of Working Structure, Working Principle, Organs, Parts and Forms.

This correspondence between the 'structure definition' category in embodiment design and the solution definition category in conceptual design open up the possibility that, in spite of the low availability of information at the conceptual stage of design, the 'solution definition' of a solution-variant might be capable of capturing its inherent uncertainties as 'configured sets' of verifiable and quantifiable outcomes of SAPPhIRE, as discussed below.

3.3 Uncertainty Category with Respect to LCA in Conceptual Design

Thus, we propose the Uncertainty category 'Solution Definition' in Conceptual design, illustrated in the adjacent Fig. 2, sub-categorised into the following:

(i) Uncertainty in the definition of **Working Structure** $\{n(S \rightarrow Ph)\}$: *A combination of several Phenomena and/or State changes*;
(ii) Uncertainty in the definition of **Working Principle** $\{oR + I \rightarrow E \rightarrow Ph\}$: *A Phenomenon or effect caused due to a combination of organs and inputs*;
(iii) Uncertainty in definition of **Organ** $\{P \rightarrow oR\}$: *An organ is the "structural context", comprising of properties and conditions that are required to activate an effect, and is dependent on parts*;
(iv) Uncertainty in definition of **Form**: *It is the perceived physical configuration or appearance of the solution, and is associated with a part or an organ*;
(v) Uncertainty in definition of **Parts** (P): *A Part is the smallest physical outcome of a solution, at the lowest level abstraction.*

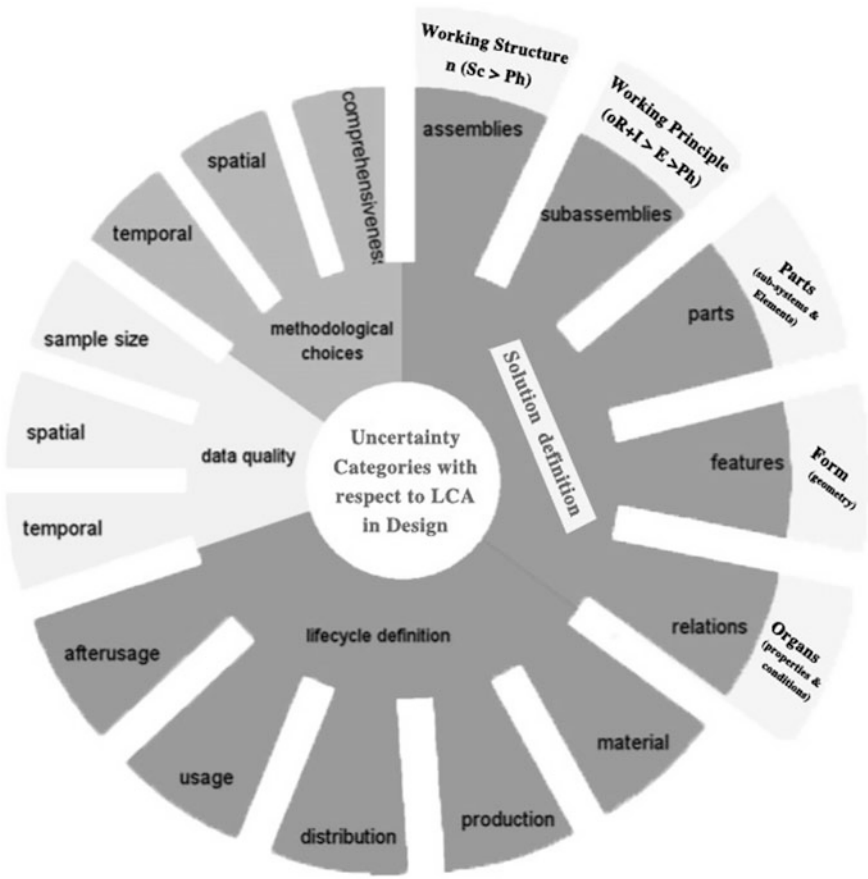

Fig. 2 Uncertainty categories with respect to LCA

4 Environmental Impact Estimate in Conceptual Design

4.1 Uncertainty Association with Environmental Impact Estimate

A solution (-variant) in conceptual design is a hierarchical organisation of solution-definition sub-categories, which as a whole can be defined as a working structure, consisting of multiple working principles that are activated by organs, (along with inputs, from outside the system) and in turn are defined by parts. Organs and parts are schematically represented by abstract geometries called form (detailed into features) which can also be attributed to the part-level. Thus, the most integral, reducible uncertainty element of a solution definition is its Part, using which one could determine the Environmental Impact (EI) of the solution by considering its five life cycle phases—material, manufacturing/production, distribution and transportation, use and after use—in an integrated, holistic manner as supported by literature. The after-use phase has strategies such as recycling, re-use, re-manufacturing or disassembly and is integral to be considered for a realising a reduced EI.

The given method of calculation at the conceptual stage draws information from the database that is in place and is part of an existing design tool having EI values collated with respect to the Embodiment stage, with inventory data made available from the later to earlier stage owing to its correspondence. Information pertaining to solution-structure with respect to life cycle is organised as a catalogue of design phenomena based on physical laws and its respective parts in the database, to allow calculation of EI.

The Environmental Impact (EI) of a Part in conceptual design, therefore, is calculated as follows.

$$\begin{aligned} \boldsymbol{EI(part)_i} &= \boldsymbol{no.\,of\,LCP\,in\,the\,i\text{-}th\,part_{l=1}\,Sum\,EI(part)_{il}\,LCP = [V_{min}V_{max}]_i} \\ &= \left[no.\,of\,Mat.\,processes\,in\,the\,i\text{-}th\,part_{l=1}Sum\,EI(Mat.\,process)_{il}\right] \\ &\quad + \left[no.\,of\,Mfg.Prod.\,processes\,in\,the\,i\text{-}th\,part_{l=1}Sum\,EI(Mfg.Prod.\,process)_{il}\right] \\ &\quad + \left[no.\,of\,Use\,processes\,in\,the\,i\text{-}th\,part_{l=1}Sum\,EI(Use\,process)_{il}\right] \\ &\quad + \left[no.\,of\,D\&T.\,processes\,in\,the\,i\text{-}th\,part_{l=1}Sum\,EI + (Dist.\&\,Trans.\,process)_{il}\right] \\ &\quad + \left[no.\,of\,After\,Use\,processes\,in\,the\,i\text{-}th\,part_{l=1}Sum\,EI(After\,Use\,process)_{il}\right] \end{aligned} \tag{1}$$

where,

EI(part)i	*Environmental Impact of part ‘i’*
LCP	*Life Cycle Phase*
Mat	*Material Phase of Life cycle*
Mfg.Prod.	*Manufacturing/Production Phase of Life cycle*
Use	*Use Phase of Life cycle*
Dist. & Trans.	*Distribution and Transportation Phase of Life cycle*
After Use	*After Use Phase of Life cycle*
[Vmin Vmax]i	*range of EI for part ‘i’*

It has been established by literature that the EI of an outcome at a higher level of abstraction is a collation of all EI of the subsequent lower-level outcomes [8]. Thus we argue that the EI estimate (and associated confidences) of any solution definition sub-category, can be represented as an aggregate of EI values of its parts, or set(s) of parts at the lowest level of abstraction, following the same logic.

The above proposed method is distinct from the EI estimation methods available for later stages—embodiment and detail—such as those by Simapro or GaBi, as they are heavily process dependant. In [12], EI values are calculated for each life cycle phase by aggregating the impacts of all processes in that phase and depends on the life cycle phase parameters as well as product structure element parameters. Whereas, with the above proposed method evaluations can occur at different levels of abstraction of the solution (-variant) without committing to a solution definition or an eventual structure. Thus, the explorative nature of conceptual design is retained.

Similarly, the uncertainty associated with these impacts can be collated to aid designers in evaluating for environmentally-benign designs. The uncertainty data taken into account encompasses both incompleteness, i.e., lack of inventory, as well as imprecision, i.e., lack of precision. However, one must note that the uncertainty associated is relative and not absolute; thus, it is imperative for evaluation that the data quality and methodological uncertainties be minimised.

Adapting from Kota and Chakrabarti [12], the Uncertainty associated with Environmental Impact of a Part in conceptual design is calculated as follows:

$$\begin{aligned} \boldsymbol{C(part)_i} &= \textbf{\textit{Data quality of EI}}\boldsymbol{(part)_i} \\ &= \boldsymbol{Dt(EI\,part)_i \times Ds\,(EI\,part)_i \times Ds(EI\,part)_i} \times 100\% \end{aligned} \tag{2}$$

where,

C(part)i =	*Confidence on the EI value of part 'i'*
Dt (EI part)$_i$ =	*temporal factor of the Data quality*
Ds (EI part)$_i$ =	*spatial factor of the Data quality*
Dss (EI part)$_i$ =	*sample size factor of the Data quality of EI value of part 'i'*

The **assumptions** for the above are as follows;

- Environmental Impact of any sub-category of a solution definition is estimated by aggregating the EI of all the life cycle processes of that sub-category.
- Environmental Impact of a higher-level solution definition sub-category is estimated by aggregating the EI of all the subsequent Solution definition sub-categories mapped to its corresponding parts, as they are causally organised in a hierarchy.
- The EI of a life cycle phase (or process) will be zero, if it has no adverse impact on the environment. However, within a given methodological framework, the confidence on this EI value will depend on the Data quality factors.

4.2 Enabling Pre-emptive, Sound Design-Decisions: Research Value Proposition

As discussed earlier, the aim of this research has been to aid designers develop environmentally-benign designs, by supporting sound design decisions at the conceptual design stage. This is done by providing designers environmental impact values with confidence levels for solution (-variants), so as to help evaluate and select the most benign solution as the concept to be selected for embodiment.

The following hypothesis is proposed to reflect the above aim*: the chances of selecting more environmentally-benign solutions as concepts can be improved by providing designers EI estimates of solution-variants at the conceptual design stage with associated confidence on these estimates.* Testing of the hypothesis using a descriptive study is detailed below.

4.2.1 Descriptive Study: Analysis of Design Decisions

To test the above hypothesis, design decisions from an empirical study of carried out earlier design session has been analysed. The design-decisions taken at the embodiment design stage for the above design session have been compared with the design-decision choices that were available at the conceptual design stage of the same session. By the end of the conceptual stage, a principle-solution is determined from amongst a number of solution-variants, though the final physical dimensions of the to-be embodied design is unavailable at this stage. For the sake of simplicity, we analysed here only the Part-level description of a solution, for only its Material life cycle phase.The unit dimension from its given parts are roughly calculated to allow an effective comparison of Environmental Impact as opposed to impact by weight of materials.

Designs (from archive above, for the same example as discussed earlier in the paper) at the conceptual and embodiment stages of the design problem 'design a multi-use furniture' were analysed, as follows;

- the Part sub-category of 'structure-definition' at the embodiment stage and its corresponding 'solution definition' at the conceptual stage were noted;
- the overall volume of the Part (material) was calculated, reproducible steps of which are mentioned in Table 1;
- the Environmental Impact with confidence value is calculated for Part solution-variants for each of the stages;
- these values are then compared for selection of the most environmentally-benign solution.

4.2.2 Observations and Findings from the Design Analysis

Observations form the analysis, given in Table 1, have been as follows.

- The designer had in fact considered three different material-classes for the Part —member of bed frame, namely—wood, ply-wood and plastic. However, he chose plastic for embodiment upon evaluating the material choices against two requirements of the product: (i) light weight, and (ii) recyclability (as a proxy for low environmental impact). It must be noted that the designer decision was not supported with EI values but was based on the assumption that, "plastic is recyclable", as found mentioned in the video protocol of the design session. The

Table 1 Analysis of design decisions in embodiment and conceptual design

	Solution—definition in conceptual design	Structure definition in embodiment design
Parts (with form/feature consideration)	Members (with approx. dimensions/scale as expected for a bed—only in drawing, not made explicit) Material: wood/plywood/plastic	– Plastic outer members/panels with stub or tenon feature – Plastic secondary members/panels with comb-teeth feature – MS C-I joint clamps and screws
Steps (reproducible) followed	Dimension of a standard bed: $6' \times 5'$ $\rightarrow$ dimension of a member: 6′ (L), 1.5′ (H) $\rightarrow$ Area of a panel = 9 sft. Also, from prior art, thickness (for ply) = 12 mm = 1/2″ = 0.04′ Approx. no of members: 6 nos. Thus, total weight of all members = 34 kgs	Dimension of outer panel = [6′ (L) × 1.5′ (H) × 1/2″ (Th)] * 2nos. + [5′ (L) × 1.5′ (H) × 1/2″ (Th)] * 2nos. Dimension of secondary panel = [(6′ (L) × 1.5′ (H) × 1/2″ (Th) − (1/2″ × 1′ × 1/2″)] * 2nos. + [5′ (L) × 1.5′ (H) × 1/2″ (Th) − (1/2″ × 1′ × 1/2″)] * 2nos. Total weight of plastic (all panels) = 20 kgs
EI value with confidence	Wood: [1.77 − 0.98] (at 60% confidence) <u>Ply wood: [4.48 − 1.02] (at 60% confidence)</u> Plastic: [16.62 − 11.458] (at 70% confidence)	Plastic: [9.78 − 6.74]; (at 70% confidence)

designer also attributed other positives to this material choice, such as ability to mould and durability.

– The volume of material calculated with the available information is higher than that actual volume of the embodied part, as is expected, as the embodiment stage added further specification to the design.

The findings were the following.

The EI value of the material class ‘plastic’ at the embodiment stage was found to be less than that in the conceptual design stage, due to the reduction of uncertainty in the volume at the latter stage. Yet, the EI values of the other two solution variant material classes, i.e., wood and ply-wood, in spite of the volume difference, were significantly lower than that for plastic, prompting ‘plastic’ to be an inappropriate selection.

– The EI value of the material class ‘wood’ was lower than that of ‘ply-wood’ and though it would appear to be the obvious choice, due it being heavier than ply-wood, if evaluated against the other requirement, namely ‘light weight’, it could be ruled out or otherwise depending on what weight was considered to be ‘heavy’ by the designer for this application.

4.2.3 Conclusions from the Design Analysis

Though EI estimation of structure definition at embodiment stage has greater information supporting it, the designer may have already committed to a decision based on other requirements which might not be as environmentally-benign.

With EI estimate of Solution-variants available at the conceptual design stage, the designer should be able to take more sound design decisions, prior to embodiment, by selecting the most environmentally-benign solution as the preferred concept (after evaluating against other requirements as well).

5 Conclusions and Future Work

For improving decisions towards more environmentally-benign designs, the inherent uncertainties associated with the conceptual design stage must be considered. As the analyses reported in this paper indicate, there is some evidence to suggest that the ‘solution definition’ uncertainty category with respect to LCA has potential to provide the Environmental impact values necessary for evaluation of solution variants at the conceptual stage itself.

It also indicates that more sound design decisions taken earlier during conceptual design stage may have profound implications on the final product, which might be better supported by proposed EI and uncertainty estimation method.

Future work involves development of a computer-based support for design decision-making for environmentally-benign designs at the conceptual stage of design. The categories maybe combined modularly as needed, however there may exist some inter-dependancies due to structure-sharing to be pursued for further study.

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Supporting Sustainable Service-System Design: A Case Study on Green-Roof Design with InDeaTe Template and Tool at Syracuse, New York

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Abstract InDeaTe Tool and Template is a sustainable design support, aimed at imbibing and improving the sustainability considerations in any design. This paper presents a case-study on 'design of green roof', a type of green infrastructure, to combat the existing issues of Stormwater Management in Syracuse. The primary objective of the design project is to design (or re-design) a green roof that will store stormwater for enough time during a reasonably strong storm so that the capacity of the Syracuse Metro treatment plant would not be exceeded. A second objective is to incorporate low environmental impact materials when designing the green roof so that the final design is more sustainable. The case study discussed in this paper, illustrates how the use of InDeaTe Tool not only improved sustainability considerations and led to many creative solutions, but could be used for design of more sustainable service systems.

Keywords Eco-Design · Design for sustainability · Enabling technologies and tools · Indeate tool and template

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1 Introduction

The city of Syracuse, located in the Onondaga County, also known as "The City that Salt built", succumbed to rapid industrialisation that eventually led to the contamination of Onondaga Lake making it America's most polluted lake. It was designated a federal Superfund site in 1994. The New York State Department of Environmental Conservation has identified that currently the two main sources of pollutants for the Lake are; (i) combined sewage overflow and (ii) stormwater run-off. The EPA (Environmental Protection Agency) defines green infrastructure as "a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits". Green Infrastructure can help solve urban stormwater challenges and includes rainwater harvesting barrels, rain gardens, planter boxes, urban trees, bio-swales, constructed wetlands, permeable pavements, green streets and alleys, green parking lots and green roofs. A Green roof is essentially a Sustainable Service-system designed for the benefit of society, environment and economy; and is already widely in place at Syracuse.

This case study illustrates the re-design of an existing green roof, to improve its sustainability considerations and address issues by using the InDeaTe Tool and Template. The resultant design is evaluated against the existing solution, to assess the improvement in sustainability considerations with the use of Tool.

2 Case Study: Overview

The goal is to assess the improvement in the sustainability consideration of the re-designed green roof and in turn, the effectiveness of the InDeaTe Tool.

This is an exploratory Case Study and key questions studied are;

(i) Does the sustainability consideration improve with the use of the InDeaTe Tool and Template?
(ii) How effective is the InDeaTe Tool and Template in supporting designer?

The underlying **proposition of this case study** is that the use of the InDeaTe Template and Tool improves the sustainability consideration of a system by supporting designers in formulating, iteratively improved List of Requirements with sustainability-focus.

2.1 Problem Brief

In Syracuse, the sewers carry both sewage and stormwater to the Metro treatment plant. When it rains, more than a light drizzle, the capacity of Metro treatment plant is exceeded. The mixture of sewage and stormwater which is in excess of the capacity must be released to Onondaga Lake without any treatment, which causes damage to the ecosystem. To avoid this problem, more places to store the stormwater over short periods of time are needed. Many kinds of green infrastructure can provide the storage.

The **objectives** of this design exercise are;

(i) to design a green roof that will store stormwater for enough time during a reasonably strong storm so that the capacity of Metro would not be exceeded,
(ii) to incorporate low environmental impact materials when designing the green roof so that the final design is more sustainable.

2.2 Design Methodology

The Design team followed the InDeaTe design process Template, where iterative GEMS activities of design are performed in each design stage while considering each life cycle phases of design.

This design exercise involved the first two design stages due to time constrain; and followed the InDeate Template's proposed design process steps to produce the following set of Deliverables; summarised in Table 1.

2.2.1 Exercise Duration

Approximately 40 h, Five days

Day 1—Introduction of team members, Design problem and Literature review
Day 2—Design Exercise with Tool—Problem Definition and Task Clarification, Site visit
Day 3—Continuation of Task Clarification
Day 4—Conceptual Design and Presentation of concept for discussions
Day 5—Design Analysis and Feedback on InDeaTe tool.

2.2.2 Participants

The Team composed of six PhD students—three of whom performed the re-design task having mechanical engineering, architecture and design backgrounds; while the other three students had prior knowledge and expertise in different aspects of green roof design. The latter three members were involved with the design of the green roof being used as benchmark.

Table 1 Case study: design methodology

Design stage	InDeaTe template: design process steps	Deliverables
Task clarification	Select system boundary	1. Preliminary list of requirements often qualitative with some understanding of their relative importance, often qualitative
	Analyse current situation to identify issues (generate requirement)	
	Using the tool/database select sustainability definitions and Indicators to be used in the process	2. Some ideas of how to solve the design problem, noted down for further use
	Evaluate the issues to find the important ones to address (evaluate/modify requirements)	
	Decide on a list of requirements and their relative importance for use the subsequent stages (select requirement)	
Conceptual design	Generate alternative ideas to satisfy each major requirement (generate solution)	1. A more concrete list of requirements
	Evaluate these ideas to select the most promising ones (evaluate/modify solution)	2. A list of possible solution-variants that could be used to solve the problem (i.e. satisfy these requirements)
	Integrate these ideas to generate alternative solution principles (generate/modify solution)	3. An evaluation of these variants for their suitability to satisfy these requirements
	Evaluate these alternatives to select the most promising solution principle (evaluate/select solution)	4. The solution-principle selected as the most promising for further development

2.3 Analysis Methodology

For the analysis of the effectiveness of the InDeaTe Tool and Template, first the design solution conceptualised was assessed following which participants analysed the effectiveness of the Tool from their experience in the design exercise.

2.3.1 Assessment of Design with Respect to Benchmark

The final design selected as concept was assessed by subject-matter expert for the following;

(i) The **Criteria for the assessment** of the design and in turn the Tool are;

- Satisfaction of Requirement
- Improvement of Sustainability consideration

(ii) **Data for analysis**: The resulting design is analysed with respect to the existing design, as benchmark, and data is in the form of List of Requirements, design sketches, design specifications and other documents.
(iii) **Units of analysis**: Qualitative analysis was performed by subject-matter experts to assess two aspects of the design;

- *High, medium, low, zero* satisfaction of requirements
- *Significantly improved, improved, not improved* Sustainability consideration.

2.3.2 Analysis of Effectiveness of Tool:

A retrospective analysis of the effectiveness of the InDeaTe Tool and Template was conducted via a Questionnaire to participants.

2.4 Limitations of the Study

- The design exercise is conducted with one team performing a single-instance of design with use of InDeaTe Tool and Template. However, multiple case studies have been performed across domains to assess the same and the analysis results were found positive and corroborative.
- Due to the dearth of a parallel exercise as control, the original design has been used as benchmark to asses the sustainability improvement of the new design. And though it may be argued that there is always scope for improvement upon an existing design, the improvement proves that the Tool can be used to re-design existing issues effectively.

2.5 Key Findings of the Study

1. The InDeaTe Template and Tool is effective for improving sustainability considerations in designs. Design assessments were conducted to determine the same and is presented in this paper.
2. The InDeaTe Template and Tool is effective in supporting the designer during the design process, this was carried out with a questionnaire, however the details are not presented in this paper.

3 Literature Review

3.1 Relevance and Need for a Holistic Support

Literature presents a number of sustainability focussed design support are available but most of them are for assessment and evaluation; such as the Swiss Ecoscarcity methods (Ecopoints). While certain tools such as DFE Workbench though well integrated with Solidworks CAD tools, is able to support designers only with respect to the a specific, in this case environmental, aspects of a design. There are also design methods that are developed that support only a specific Life Cycle Phase such as the Use-phase [1].

Literature also notes the existing "interaction of methods and tools at various steps in the process" of design and further stresses on the need for interaction between design methods and computer-aided tools to support decision-making [2]. Lopez-Mesa [3] enumerated potent findings about the knowledge and use of design methods in practice and highlighted that only a few methods are 'widely and systematically used' while most are unaware of the availability of other methods and believe that abundance of time is required. However, she notes that implementation of methods provides support to an array of tasks during the design process and leads to consideration of a large number of ideas. Lopez-Mesa further stresses on the increased positive contribution by a method upon the design when it is in a computer based system [3]. Thus, there is need of a computer-based support that encompasses all three dimensions of sustainability across the entirety of the Life cycle of the design.

3.2 InDeaTe Tool and Template: A Novel, Holistic Design Support

InDeaTe Template and Tool, is a knowledge-driven Sustainable Design process support, aimed at imbibing and improving the sustainability considerations in a design. It comprises of two elements—a sustainable design process Template, and a sustainable Design Database—that work synergistically to support the designer on a user-friendly, computer interface. The Template and the Design Database ontology is based on the ACLODS holistic framework [4] which proposes dimensions—Activities, Criteria, Life cycle phase, Outcome, Design Stage and Structure—essential for life cycle development of a design.

The InDeaTe design process Template offers an overview of the design process and provides a generic guideline to follow as the design process is carried out. There are four stages of design—Task Clarification, Conceptual Design, Embodiment Design and Detail Design [5]. And every design has five Life cycle phase, which are; Material, Production, Distribution and Transportation, Use and

After Use. The Template encourages designing for the entire lifecycle of the system, with the aim of making it more sustainable. It guides the designer to perform suitable Activities of design, i.e., generate-evaluate-modify-select (GEMS) in each Design stage, at the intersection of every Life Cycle Phase.

3.3 Green Roofs: A Literature Survey

A green roof is a green infrastructure being promoted through incentive programs for construction for being a sustainable solution to the plaguing issue of combined sewage overflows across cities in America. Green roofs have the ability to store a portion of storm water, attenuate stormwater run-off into the sewage system and allow evapotranspiration, thereby reducing the load on the common sewage system and deterring sewage overflow, and eventually protecting ecosystem damage. Green roofs also reduce energy usage for cooling and urban heat island effects, and provide wildlife habitat.

A typical green roof comprises of layers of drainage course, growing substrate and drought resistant vegetation atop a waterproof membrane of the roof floor, and may have geo-synthetic layers interspersed to limit sediment intrusion into drainage layer and the plant rooting. They maybe extensive or intensive, depending on the thickness of the substrate layer. Extensive green roofs are more common as they are cheaper to install, require less maintenance and are lighter, with approximately 15 cm of substrate and short rooting vegetation. The hydrological behaviour of a green roof is affected by construction type, growing substrate depth, vegetation type, areal coverage, as well as the local climate which determines the precipitation pattern and the rate of evapotranspiration [6]. Owing to the substrate layer with low thermal conductivity and high thermal mass, green roofs behave as natural insulation and reduce energy consumption of buildings. They can further be used to reduce the urban heat island (UHI) effect of big cities as the vegetation reduces solar heat gains due to its high albedo and evapotranspiration. However, their efficacy reduces with high insulation of the building roof and requires adequate calculations for improving performance [7].

As green roofs emulate natural habitats, Dvorak and Volder [8] published a 'Chronological summary of green roof vegetation findings' for North America based on the eco-region of the location and further enumerated effective plant species by type and location. They further stated that "succulent-dominated green roofs are well-suited to survive the extreme conditions found on rooftops and prefer shallow substrates from 7 to 10 cm thick for many of the eco-regions investigated" [8].

The green roof for the re-design exercise was an extensive, built-in-place roof with sedum as the primary vegetation though certain other sporadic species were also found to have grown. It had slopes designed perpendicularly to its length along the centre and were fitted with french drains as would be the norm for a regular roof. Also, the roof was capable of withstanding the additional load of the green roof and more importantly the expected storm-water to be retained, being heavily insulated for snow-load. Thus from site conditions and literature review, it was concluded that the existing Sedum vegetation was ideal for the given conditions.

4 Design Exercise

4.1 Task Clarification Stage

In this stage, the design team well defined the problem statement with the intent to identify a preliminary list of requirements.

Step 1: The team **Selected a System Boundary** as prescribed by the InDeaTe Template. Due to the propensity of time and complexity of the issues, certain aspects of green roof were identified to be outside the system boundary, such as—Composition of growth medium, Species of vegetation and Methods of planting the vegetation, and were taken as is for the re-design exercise.

The teams together identified certain other constraints, as listed below;

- usable flat, surface area for installation and thus the volume for water retention
- snow-load capacity of the roof to bear the volume of retained storm water
- existing slope and drainage system on the roof
- the location of the green roof (physical and visual access)

The areas of intervention identified were;

- means to retain storm water
- type of irrigation to get water for the plants for the first few months
- methods of laying down the growth medium
- maintenance of green roof after the vegetation is planted
- increase social acceptance of green roofs

Step 2: The team **analysed the current situation to identify issues** and generated (G) requirements.

The existing system had **three primary issues** and each of these in turn had the following **lifecycle issues** to be addressed;

- **The lack of adequate retention of storm water** resulted from a Production phase issue. During the installation of the green roof, the existing french drains common to other flat roofs, were not removed, which leads to the issue of rapid drainage of the precipitated water into the main sewer line and defeats the purpose of the green roof as a retention unit
- **The poor visibility and access to the roof**, inspite of being on a public building, results in low social impact. Also, the diverse eco-system on the roof

attracts a large number of insect, bird and small animal species causing social nuisance. Together these adversely effects the Use phase and has lead to low social acceptance

– **The high cost of installation** causes socio-economic dissent and hinders the overall lifecycle of the system and in turn negatively impacts the environment
– Also, due to the use of fine plastic mesh atop of plantation as wind-cover, small bird get caught and lose their lives. This is displeasing and is a Use-phase issue.

In order to well-define the problem, the designers formulated a **Solution Neutral Problem Statement (SNPS)**—*To re-design the green roof system having high stormwater retention, controlled run-off and increase social acceptance towards its installation in Syracuse.*

The design team then turned to the Tool and **chose the TBL scope** as—environment, society and economy, for the issues already described above. The Tool provided a list of Sustainability Definitions from which the designers **selected Sustainability Definitions, Principles and Indicators** for their design process.

The team found the following definitions to be appropriate: **World Bank** [9], **IISD** (International Institute for Sustainable Development) [10], **Sustainable Seattle** [11], **Sustainable Arizona** [12], and **Dillard et al**. [13].

Upon selecting the definitions, the Tool further provided a set of **Sustainability Indicators** that would be used to operationalise the selected definitions. These were;

– Land (Environmental Indicator): Fertiliser use efficiency, Use of agricultural pesticides [14];
– Water (Environmental Indicator): Presence of faecal coliform in freshwater, Wastewater treatment [14]; Urban wastewater treatment [15]; Index of heavy metal emissions to water, Eutrophication [16];
– Waste (Environmental Indicator): Waste treatment and disposal (as per sectors) [14]; Initiatives to mitigate environmental impacts of products and services, and extent of impact mitigation [17]; Eco-toxic substance effluent [18];
– Health and Safety (Social Indicator): Life cycle stages in which health and safety impacts of products and services are assessed for improvement, and percentage of significant products and services categories subject to such procedures [19];
– Investments, costs (expenditures) and consumption (Economic Indicator): Environmental expenditure [20]; Waste treatment costs [18].

Step 3: These Indicators prompted the generation of preliminary requirements and the teams together conducted an e**valuation of issues** to find the important ones to address.

To prioritise these requirements, the design team selected **Quality Function Deployment (QFD) Method** from the Design Database and calculated the relative importance of the requirements by Weighing factors on a 5-pt scale to determine the priorities of the Requirement, as shown in Table 2.

Table 2 Task clarification: weighting factors to develop prioritised LoR

Weighing factors	High retention capacity	Reduce pollution of run-off water	Control over run-off rate	Cause no harm to the fauna	Prevent substrate material from blowing away	Better visibility and marketability	Easy maintenance	Sum
High retention capacity		1	0.5	1	0.5	1	0.5	4.5
Reduce pollution of run-off water	0		0.5	1	0.5	1	0.5	3.5
Control over run-off rate	0.5	0.5		1	0.5	1	0.5	4
Harmless to the fauna	0	0	0		0.5	0.5	0	1
Prevent substrate material from blowing away	0.5	0.5	0.5	0.5		1	0.5	3.5
Better visibility and marketability	0	0	0	0.5	0		0.5	1
Easy maintenance	0.5	0.5	0.5	1	0.5	0.5		3.5

Step 4: Thus, the team fulfilled the **Task Clarification Deliverable** of formulating a **Preliminary List of Requirements,** as given below;

(i) Increase storm water retention capacity
(ii) Control stormwater run-off rate into sewers
(iii) Reduce pollution of run-off water
(iv) Prevent substrate material from blowing away
(v) Easy maintenance
(vi) Cause no harm to fauna
(vii) Better visibility and marketability

4.2 Conceptual Design Stage

In this stage, the design team explored a number of solution-variants and worked towards selecting the solution-principle or "concept".

Step 5: The team **generated (G) alternative ideas to satisfy each major requirement** and to do so selected the Brainstorming Method from the Database. The result was a number of ideas for each of the requirements, as given below in Table 3.

Step 6 and 7: These **ideas were then evaluated** to see which were feasible and which ones would have greater effect. The design team used the **Morphological Chart Tool** from the Database. It was further used to **combine solutions and generate** five distinct solution-variants, namely #1, #2, #3, #4, #5, as given below. These variants were sketched as part of the generation/modification of solutions.

Step 8: The design team further **evaluated the solution-variants** by using the **Quality Function Deployment (QFD)** Method from the Design Database, where the solution-variant attributes, developed from the previous list of requirements, were ranked based on their satisfaction of requirement and compared. The selected concept was Solution-variant 1 to be embodied.

5 Key Findings

5.1 Design Assessment

A number of design solution variants were presented to subject-matter expert to assess the final concept design with respect to the benchmark for requirement satisfaction and improvement of sustainability consideration of the Service system designed. This is presented in Table 3.

Table 3 Conceptual design using brainstorming method

Requirements	Ideas generated during brainstorming					
High retention capacity	Solution-principle: Conceptual sketch Alternative absorbent (foam) materials	Increase the thickness of substrate/drain layer	Vertical green roofing	Reservoir	Water absorbing silicone balls	Arduous drainage path
Control run-off rate	Flow rate sensors	Automated control valves on drains	Compartmental storage tanks	Timed water release mechanism (coordinating with urban flow, post-storm)	Drip irrigation from reservoir	Pass it into ground water reservoir
Reduce pollution of run-off water	Install filtration system (activated carbon)	Organic fertiliser/manure	Run-off water quality monitoring	Plant Ryegrass, Lolium multiflorum- absorb relatively large quantities of certain types of toxics such as PAH (polycyclic aromatic hydrocarbons)	Phytoremediation - Plants that absorb pollutants from water in drainage sump (hyperaccumulators)	Increase thickness of the substrate
Prevent substrate material from blowing away	Resinated pieces that stick together	*Mulch as a top layer	Moss			
Easy maintenance	Improve the access	Maintainance Drones		*Note: Green roofs overall, and especially extensive ones, do not require high maintenance*		
Cause no harm to the fauna	Lighter wind blanket material	Easily breakable wind blanket material	Eliminate wind blanket	Wider modular plastic frames for tacking + decomposable blankets sheets in between		
Better visibility and marketability	Locating green roofs on medium height bldgs.	Providing public access (consider dynamic load)	Smaller green roofs on tiled sloping roofs (affordable & appealing to residents)			
Vegetation	Sedum *Note: as in existing, good choice supported by Literature*	Aloe, Delosperma, Euphorbia (Desirable for Hot and humid)	*Mulch—increase water retention and as it decomposes enriches the soil			

Table 4 Assessment of design—proposed solution benchmarked to existing solution

List of requirements	Existing solutions (Benchmark)	Proposed solution concept	Requirement satisfaction	Sustainability consideration
High retention capacity	– Single layers of plastic profiled element and media	– Increased thickness of substrate/drain layer and varying layer grain	High	Improved significantly
Control run-off rate	– Presence of french drains, increase the rate of run off	Timed water release mechanism (coordinating with urban flow, post-storm)	High	Improved significantly
Reduce pollution of run-off water		Phytoremediation—plants that absorb pollutants from water in drainage sump (hyper-accumulators)	Medium	Improved
Prevent substrate material from blowing away		– Easily breakable wind blanket material of thicker borders and thin, perpendicular strands of organic fibre	Medium	Improved
Cause no harm to the fauna			High	Improved significantly
Easy maintenance		– Improve the access	Medium	Improved
Better visibility and Marketability		– Locating green roofs on medium height buildings, and along the facade	Medium	Improved
Assessment			Satisfied	Sustainability improved

The results of the two criteria were in consensus which may be viewed as a validation of the InDeaTe Tool and Template as an effective support to improve sustainability of a service system (Table 4).

5.2 Analysis of Tool

The results of the Questionnaire were overall positive with designers stating that they found the Tool useful

InDeaTe effectively supported the design team to;

- Identify many, new or otherwise neglected, requirements across social, economic and environmental aspects
- Conceptualise a large number of design solution-variants
- Select a "good" concept hich satisfies the requirement and achieves improved sustainability considerations.

6 Conclusions

It is concluded that InDeaTe Tool and Template is an effective sustainability design support as it improved sustainability considerations of the green roof Service-system and in turn was found useful by the designers. Thus, the InDeaTe Tool and Template is recommended for design of more sustainable service systems.

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‘What Ideality Tool’ (WIT) for Product Design Briefs

Transitioning from a Static Flowchart to a Dynamic Automation Tool

Alon Weiss, Iko avital, A.K. Das, Mazor Gedalya and Pratul Ch. Kalita

Abstract This paper discusses the relationship between the ‘WHAT’ and ‘HOW’ concepts in the design process through the innovative ‘What Ideality Tool’ (‘WIT’). The abstract tool draws on nature ideality principles, crossing from the traditional static flowchart model to a dynamic automation tool, promoting design procedures by focusing on the ‘WHAT’ as a creative engine, instead of skipping ahead to the ‘HOW’. Many product designers rush into a design solution without thorough analysis of a product’s intended purpose. Applying ‘WIT’ in the ideation stage to create the designer brief serves as a preemptive tool for handling cognitive obstacles; this results in the paradox wherein the more experienced a designer is, the less flexible the design approach becomes. Hence, their range of ideas essentially becomes their ‘fixed design style’. The ‘WIT’ approach enriches designers’ mindset abilities, expanding the creativity flow by exposing distant connections, and promoting sustainable attributes necessary in today’s market.

Keywords Design process · Creativity · Checklist · Ideality · Biomimetic

1 Introduction

To compete in today’s market, product designers (PDs) must implement sustainability principles from the start of the design process to offer solutions for current needs, without compromising those of future generations [1]. Therefore, the PD is considered exclusively accountable for the design process, product and playing a key role in ensuring sustainable design via the physical scopes of product design, non-physical scopes of meta-design, and a comprehensive multi-perspective, holistic view [2]. Current design challenges are often too

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complex and poorly defined, so they cannot be solved using traditional methods [3], meaning the process must be adjusted accordingly [4]. Every design process begins by identifying potential solutions from the "WHAT" stage, describing the function of the design, and the "HOW" stage, describing the method for implementation, which together form the brief and have considerable influence over the result. Research has shown that investing in the ideation stage has a high correlation (>70%) with the quality of the final product. On the other hand, resources necessary at this stage are relatively limited (10% of the total cost of the project). Currently, the industry allocates only about 15% of total design time for the ideation stage, when it should stand at 20–25% to avoid requiring costly changes at a later stage [6]. With this in mind, PDs must strive to avoid executing their first concepts as doing so means they miss an opportunity to expand the "WHAT", as they rush into a specific design solution (the "HOW"). This phenomenon, known as the "Design Process Paradox" [6], is defined as the natural cognitive tendency to comprehend the way things function by adjusting customer's functional requirements, and then redirecting the design towards the "HOW". Understandably this limits the range of potential solutions [7]. This "WHAT" analysis helps PDs focus on product requirements, however it does lead to a paradoxical obstruction of creativity, confining potential attributes. Hence, by releasing the "Design Fixation", the PD can move away from safe zone thinking patterns [5]. In both cases, which are evident among experienced PDs with extensive knowledge, this results in less flexibility, as their initial vision becomes the preferred design choice. Their limited range of ideas essentially becomes, as I have termed it, their 'fixed design style' [10]. During my 12 years as a senior PD, I have witnessed first-hand the cognitive obstacles in the design process that lead designers towards a narrow funnel of creative flow that limits the solution space. The "WHAT" stage is therefore critical; formulation of the "WHAT" helps PDs plan the "HOW" and select the ideal design. Since PDs work in an intuitive, random manner, they tend to prefer dynamic handling of the design process. However, constraints can change, and PDs are often required to make assumptions that comply with these dynamic limitations, while maintaining creativity and a way to integrate new concepts. The design processes are defined by the PD's intellectual ability. However, this emphasizes the need for external design tools that enhance cognitive abilities and allow us to better cope with current challenges [8]. Currently, there is a shift toward the use of Design Automation tools [9], which offer the added value of optimizing performance speed in routine tasks. Nonetheless, the design process requires abstraction of solution requirements, requiring the exploration of hidden potential solutions and the combination of multidisciplinary ideas to find an ideal design—traditional automated tools remove the opportunity for this type of lateral thinking. Although there is no single solution, the process calls for meticulous attention to detail, strong analytical abilities and a flexible and broad systemic approach [6]. The PD's role includes both the artistic and engineering domains, while nature serves as the cradle for developing Design-by-Analogy solutions—a powerful tool for encouraging innovation based on the use of analogies associated with cognition and creative thinking [12]. Research shows that the greater the distance between domains, the more innovation can develop [13]. Exposure to nature provides unusual and significant multidisciplinary solutions, thereby increasing the novelty of the design concept, without decreasing its diversity [14]. It is these solutions which offer the most potential for innovation and sustainability [15].

2 Nature as a Model, Tutor and Scale

Wolfgang von Goethe (1749–1832) stated, “In living nature, nothing happens that is not in connection with a whole” [16]. Natural systems operate within restricted sets of conditions, minimizing waste and irreversible damage. They must also demonstrate exemplary sustainable strategies and design principles in order to “achieve more with less” due to the competition for resources [23]. Bio-inspired sustainable design tools are based on simplifications of patterns found in nature [7], offering ways to support a global bio-inspired design approach [17] and to encourage conservation of nature as a source of inspiration for innovative solutions [18]. These tools support the designer’s access to nature as a source of design inspiration, and offer a systematic method for identifying relevant biological systems and abstracting their design solutions [19]. The Biomimicry approach focuses on innovative solutions, on learning about and devotion to nature, and is a part of an overall nature-inspired design strategy [20]. Moreover, it integrates nature into products needed by humankind [21]. Aiming to achieve sustainability, and was applied within a commercial business framework, demonstrating remarkable influence in the industry [11]. ‘WIT’ serves as a Design Thinking Tool to generate the designer brief. Through biomimicry, the tool emulates nature’s holistic process. Ideality principles in TRIZ (the theory of inventive problem solving [24]) utilize nature’s strategies to increase benefits and reduce costs, thus allowing the Ideality model to accelerate success [22]. Other examples of TRIZ are the Ideality based Tool aimed for Sustainable Design [23] and Eco-Innovation via assimilating Biomimetic with Ideality principles and Evolution method [24]. This relationship between sustainability and Ideality served as the basis for the evolution of applied eco-strategies for the achievement of product innovation, while nature Ideality strategies can serve as sustainability tools [23]. That said, these bio-inspired sustainability tools do not specifically incorporate PD brief methodologies. Therefore, these tools must be adapted to PD in order to improve Design Thinking efficiency by implementing sustainable guidelines to bridge the existing gaps.

2.1 'What Ideality Tool' ('WIT') for the Product Design Brief

This tool is based on principles from two main domains: product design briefs and the Ideality design principle. The interaction between these realms encourages PDs to examine how each principle can be realized in each design brief, first by focusing on the "WHAT" aspect and then the "HOW" component. The Form-Follows-Function concept [25] was implemented during the Industrial Revolution and, since then, the industry has been trapped by the assembly line structure of mass production, which naturally results in design constraints. Following recent technological advances, new opportunities were made available for experts who can control and maneuver material attributes for finding direct innovative solutions for implementation, designers were able to access knowledge they never had before [26]. As a result, PDs can now re-structure "Form-Follows-Function" as the new nature-inspired design strategy frontier for the product brief, as I have termed it: 'Attribute Follows Form Follows Function'. This strategy allows PDs to manipulate design properties; creating a new customized design discipline that responds to the environment, redefines terminology and handles future constraints. Another technique for distinguishing the "WHAT" from the "HOW" is made through the use of syntax and language and searching through all relevant adjectives relating to its attributes, instead of simply focusing on function. This process prevents falling back on the "HOW", offering precise guidance and leading to varied innovative concepts. WIT methods utilize the Ideality design principles, in order to generate a broader effect within existing constraints.

The model promotes identification and expansion of the opportunities embodied within the future solution, as per the product life cycle analysis checklist. This

Table 1 Ideality patterns: strategies and design principles analysis

Criteria	General strategy	Design principle
Increasing benefits	Multi-functional planning	Resource saving: expanding the functions associated with one structure in the product
	Amplifying	Increasing product's efficacy and impact: • Creating an amplified effect of the system's components (accentuation, duplication, expansion, collection, etc.) • Increasing interaction and synergy with the environment
Reducing costs	Defense	Preventing disturbances, malfunctions and system damages: reducing surface area, friction, load, turbulence, etc.
	Opportunistic	Preventing waste of existing resources: • Matching structure to function • Symbiosis—reciprocal interaction between product and environment • Utilizing environmental resources
	Effective resource management	Preventing waste of existing resources: Synchronizing system components

allows the PD to explore challenges in depth to ensure that no necessary parameters have been forgotten, as well as flagging any knowledge gaps which may need to be resourced to complete the process [4]. The structure of the model provides a useful starting point: following client's brief, within a set of constraints.

2.2 How Was the Model Developed?

The model, a derivative of the sustainability ideality tool [23], was developed to cope with main cognitive obstacles and adapt to the field of PD via modification of the terminology. Several test runs of the model were performed. The tool was initially a static series of questions for the user. The format proved useful but tedious, requiring the user to sift through a great mass of data. In the second stage, the model was a dynamic Excel sheet, built as one modular structure question, assembled by the user (Table 2).

Table 2 Comparative analysis of WIT methods

	Static flowchart model [7]	Dynamic automated model [10]
Structure model	Static: The question's structure can be applied multiple times and has numerous choices from which the user can select	Interactive, dynamic, analytical Excel-based program, formulates a singular modular question containing a cartridge of main traditional soft, hard attributes and the ideality design principles. The question structure can be applied multiple times offering users a range of choices
Visual	Clean design of a diagram consisting of a Venn diagram, demonstrating much of the exposed information simultaneously	Interactive design unit in the modular question format. More relevant data is presented as the user progresses This format improves the tool's usability by displaying each variable visually, therefore assisting users' comprehension of complexities and potential solutions
The question format algorithms	Scenario-oriented questions such as "what", "which", "why", "where" and "when" aim to increase the number of functions associated with the Product Brief Checklist in order to increase product ideality	Which attribute will support the "WHAT" attributes and add value through the Ideality design principle? Practicality of the solution will be presented via: "HOW" it can be implemented?

2.3 Transitioning from a Static Flowchart to a Dynamic Automation Tool

The static flowchart consists of a checklist divided into topics and sub-topics structured as questions. Directing PDs inwards, emphasizing various user scenarios and product usability. The checklist deals with elements such as project management, regulation, production, marketing, user experience, prototyping, product features and their sub-categories. This operating process is performed via a framework of scenario-oriented questions where the objective is to reach the most extensive range of possibilities in the search results [7]. However, by contrast, the dynamic automation tool lies in the Automated Modular Question stage, under the following sections (Table 3): (1.1) Product brief checklist, Category and Subcategory (1.2), the "WHAT" (2.1), added value (2.2), Ideality Design Principle (3), inspirational image search (4), and the "HOW" (5). Their answers form the research question. The second iteration displays each variable visually. The checklist category and subcategory are selected first and they focus on the hard, soft and sustainable attributes. Despite the significant variation between tasks, the checklist allows users to adjust the system to their own needs and even add new attributes. In the second part, users select the "WHAT", and in the third part, users select the most fitting ideality design principle. These principles are divided into two main groups: Cost reduction and increased benefits, each with its respective design principles (Table 1). Together, these three stages result in the formulation of the Automated Modular Question (Fig. 1), which is the design infrastructure; this serves to enhance the design process. By increasing the number of attributes, PDs can increase efficiency and amplify various parameters for a more sustainable final product, all while keeping the ideality principles in mind [10].

The following algorithm explains its implementation: ***Which attribute will support the <u>"WHAT" attributes and add value</u> through the <u>Ideality design principle</u>? Practicality of the Solution will be presented*** **via:** ***"<u>HOW</u>" it can be implemented?***

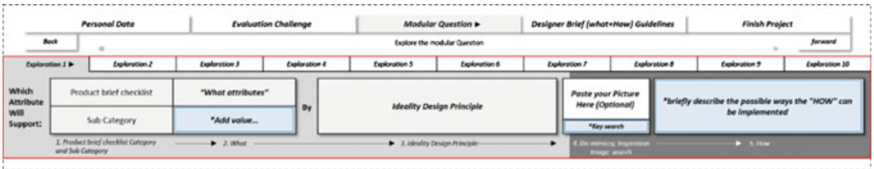

Fig. 1 Screenshot of the Modular Question stage in the excel program

Table 3 The Modular question structure method

<table>
<tr><td>1.1 Product brief Checklist</td><td>2.1 "WHAT" Attributes</td><td rowspan="2">3. Ideality design principles</td><td rowspan="2">4. An analogical image</td><td rowspan="2">5. "HOW"</td></tr>
<tr><td>1.2 Sub category</td><td>2.2 Added value</td></tr>
</table>

2.4 Research and Test Case Description

The same design challenge was assigned to the focus group which included experienced PDs in various fields; the group was divided to into a test group and a control group. The control group used various traditional Design Thinking methods [3] while the first test group used the Static Flowchart model [7] and the second test group used the Dynamic Structure model [10]. Background: In light of the increased usage of public transportation, many people pass through public transportation in metropolitan areas requiring a smart and effective waste disposal system. The task was to create a design brief concept for waste disposal in public stations.

2.5 Results

The Control Group: Individual PDs used traditional methods [3], focusing mainly on standard requirements such as design, functional, separation of recycling and waste (Tables 4 and 5).

Table 4 Example of the repeated outputs generated via varied methods

Category	Description
Form	Integration into existing furniture or separate object. Colors and symbols to clarify use
Technology	Add voice system to greet/thank users, to encourage recycling, or add a fun factor (e.g. via an app)
Maintenance	Easy to clean
Structure	Simple opening mechanism for quick disposal

Table 5 Only one PD was able to reach a more in-depth thinking level

Category	Description
Form	The bins can be integrated in station's furniture or as a separate object. Use of colors and symbols can make clearer how to recycle, and indicate where to throw each type of trash
Technology	Voice indicator that will greet people, or reward people by saying "thank you" which will stimulate good behavior and encourage people to recycle. It can also be transformed to be fun such as implementing a game via the use of an App
Maintenance	Has to be easy to clean. Material has to be easy to clean and to maintain it
Structure	Opening should not be too big or too small. Design needs to be efficient to attract passers-by
Effective resources	Preventing waste of existing resources: Synchronizing system components

The Test Group: Individual PDs tested either the Static flowchart model or the Dynamic structure model, focusing on a variety of human-usage scenarios. When creating the design brief, the model served as a design-thinking framework, forcing the PDs to consider a wide range of aspects in the design of a futuristic trash bin concept. This focused on the "WHAT", and explored the product-assembled requirements from the checklist. The PDs produced a unique thought process, steering them away from dealing first with the "HOW", and guiding them towards more sustainable concepts (Tables 6 and 7).

Table 6 The Static flowchart being explored simultaneously via several ideality principles

Bins to be made from recycled materials and placed around the station	
Structure	No plastic trash bags, instead they will be made of the material they are designed to hold
Functionality	When full, bins themselves are recycled: bin and trash will be compressed to create new bins. The concept is based on circular recycling with compressors at each station

Table 7 Example of the outputs generated via the Dynamic structure being explored separately via several ideality principles

"WHAT"	Flexibility and highly elastic; via the main ideality category of Reducing Costs, defense strategy	
Aim	Preventing system damages, Analogue image of Pangolin (a structure that can fold into a ball-like construction)	
"HOW"	The structure of the bin would allow formation re-structure: when containing a small amount of trash it will remain small and will increase in size, as it gets fuller. The material of the bin allows it to shrink and grow according to content size	
"WHAT"	Sound design, via main ideality category of Increasing Benefits, Multi-functional planning Strategy	
Aim	Resources saving. Used analogue image of talking parrot	
"HOW"	The bin will have voice indicator for the user to encourage usage. It will be designed in a way that, when used, speech or music to encourage the user through praise will be heard	
"WHAT"	Functionality reduction, via main ideality category of reducing cost, opportunistic strategy	
Aim	Avoid waste of existing resources via symbiosis—reciprocal interaction of product and environment. Used analogue image of pearl	
"HOW"	The oyster's pearl soft protein materials increase its strength. In a similar way, the waste can create the structure of the bin	

Table 8 Criteria and measurement

Criteria	Measure type
Checklist usability level	A measure of the checklist used during the design process
Creativity level	A measure of high or low level of creativity; high level characteristics are demonstrated by motivated innovative patterns, thinking with intuition expression, forward invention and relevant associative with unusual thinking concept in the solution space
Analogies level	A measure of the distance and the types of analogies used for idea creation
Evolution level	A measure of the output evolution relative to other outputs proposal as 'better than principle'
'Fixed design style'	A measure of the PDs cognitive obstacles phenomenon existence

2.6 Criteria and Measuring Process

The following criteria and measuring were defined with rankings scale between standard, advanced, revolutionary degree levels and between exist and not exist (Table 8).

2.7 Discussion

Following the test, it was evident that the use of both 'WIT' methods forced the test groups to focus on the "WHAT" before they focused on the "HOW" and produced higher results in several measurers in comparison to the control group (Table 9).

The PDs who utilized traditional methods generated relatively standard concepts. In comparison, the PDs that used 'WIT' methods did create similar concepts but had higher performance creative levels, in particularly the Dynamic structure model that increases the PDs' **creativity to revolutionary level**. Having the **checklist usability criteria visible and visual throughout the process guided the test groups in their design, whereas the control group relied on memory to retain the parameters** for more a sustainable output, stemming from the ideality angle performance, and using an **advanced level of analogies**. Combining this with the checklist evaluation led to more in-depth thinking within the search scope. The current inclination towards sustainability is evident also in traditional tools, however the dynamic tool's constraints force the user not only to adopt sustainable designs, but users are also directed towards **evolutionary concepts at an advanced level**. Additionally, the test group using the 'WIT' reported that their outputs were unique and unconventional, breaking their routine thinking patterns, allowing them to leverage them for new search space. By contrast, the control group's design fixation was evident in their standard concepts, and the tendency to stay within the

Table 9 Comparative analysis of approaches

	Traditional methods [3]	Static flowchart model [7]	Dynamic structure model "WIT"
Primary Hypothesis:	*Using the tool promotes broad, in-depth creativity flow*		
Secondary Hypothesis:	*Maintain and improve the creativity flow*	*Evolve the creativity flow*	*Revolutionize the creativity flow*
Number of PDs	3	1	1
Experience	5–12 years	10 years	15 years
Intellectual effort required and time invested	Requires systematic thinking capabilities. An average of 30 min	Complex and requires systematic thinking capabilities. Time spent: 2 h	Complex, requiring systematic thinking but at a faster pace. Efficient, time spent: 3 h
Outcome	Listing linear concepts	User-created Manually sketched Flowchart, listing possible attributes and means of implementation	Automated Design brief inspiration board, with chart of recommended attributes, images and links to the means of implementation.
Checklist Usability level	Standard	Advanced	Advanced
Creativity level	Standard	Advanced	Revolutionary
Analogies level	Not used	Standard	Advanced
Evolution level	Standard	Advanced	Advanced
'fixed design style'	Yes	Non-existent	Non-existent

familiar, comfortable, safe zone. Therefore, the 'WIT' activity measured performance without the existence of a '**fixed design style**'. The tool integrates design strategies from nature that are simplified in order to be accessible to PDs. 'WIT' therefore penetrates deeper into the various disciplines, via a unique thinking angle which promotes sustainable pattern outputs. The dynamic tool's strength lies in creating parallel thought processes, while generating other contextual concepts and multiplying design possibilities, instead of just predicting solutions [9]. By using the modular questions, the designer can focus on the "WHAT" and then on the "HOW" in a linear fashion. The test also revealed that the tool requires, on average, four times more time than traditional methods, and demands greater intellectual effort than traditional methods. Traditional methods focus on preserving existing conditions ("must have" requirements are the most common ones) while aspiring to maximal functions. However, the 'WIT' method instead focuses on the search and identification of search components and system optimization for selecting attributes that may be relevant at a later stage, and which stem from the revolutionized creativity flow. The tool reinforces the role of the PD as an ambassador of social sustainability.

2.8 Summary and Conclusions

Although both 'WIT' and traditional methods engage PDs and encourage thought expansion, the constraints of the automated 'WIT' method lead to greater performance due to repeat integration of analogies that promotes the wide and depth creativity flow, and encourage the concepts evolution level. The dynamic mode has proven to be more effective and efficient, making terminology more accessible, although it is more time consuming. The 'WIT', as a bio-inspired sustainability tool, aims to bridge the 'fixed design style' gap by increasing the scope of ideal concepts generated using ideality principles as problem-solving strategies, as well as the utilization of multidisciplinary knowledge through cross-referencing, including visual search methods. By applying the tool directly, the PD moves beyond their normal thinking pattern scope, enabling them to evaluate product parameter requirements. Amplifying PDs' cognitive capacities by bringing hidden connections to the surface and turning each attribute into an access point for sustainability, this acts as a wide lens for capturing nature-inspired solutions. Despite this, the method still requires extensive systematic knowledge and flexible thinking to help PDs develop fully suitable designs.

2.9 Suggestions for Continued Research

Integrate sustainable attributes, categorized as either ***Engines*** that drive change or ignite evolution or ***Brakes*** that maintain the status-quo would help. The resulting tension in the design world can then be a source for further exploration.

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Holistic Socio-environmental Design: Practices Through Making, Craft, and Historicity

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Abstract Situated in the postcolonial paradigm of India, the paper is an attempt to delineate socio-environmental approaches from an ideological and cultural ground of design practice. The cases are based on food, textile, product, building and urban design practices which contribute towards a holistic socio-environmental design framework. The systemic repercussions of design and decisions in the making of physical cultural objects directly influence how a society operates and functions. The research underlines the significance of an object's making, craft, and historicity to discover holistic and inclusive dimensions of culture, society and environment as it relates to humans.

Keywords Socio-environmental design · Making · Craft · Historicity · Holistic design · Sustainability · Design · Development

1 Introduction

Newly independent India was a part of various notions of underdeveloped groups like the third world, the global south, and the non-aligned. Post-liberalization (after 1991) India has been associated with progressive organizations like BRICS, G-15,

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and G-20, conveying a sense of graduation from underdeveloped to the developing. The diplomatic will to a new alignment with the group of 'developed' or 'rapidly developing' exhibits a perception of its development. As Menon and Nigam [1] noted, the policies of 1990s further globalized production and consumption. At the same time, this further obliterated the ascetic, revivalist and introspective visions of Gandhi [2] as it opened the gates for foreign imports [3]. In India, a fascination towards modernity and technology (as an absolute end) has created a new culture. This has formed an outlook that often discounts holistic development through social, cultural, environmental, anthropological and historical dimensions.

It is an often that the need of sustainable processes only emerge when a society apprehends its unsustainable consequences. Often visibly rational solutions that are disconnected but immediate are seen as an end in itself as opposed to the notion of continuity and a work in progress. The systemic repercussions of design and decisions in the making of cultural objects that define our physical environment directly influence how a community, city or country operates and functions. The paper underlines the significance of an object's making, craft and historicity to discover holistic dimensions of culture, society, and environment as it relates to humans.

2 Sustainability: Meanings and Practices

It is critical to discuss the concept of 'sustainability' in the Indian context and its local expressions. The literal translation of the word 'sustainability' in Hindi is *Nirantarta* (continuity). This concept further calls for approaches through which human and nature can co-exist till eternity. The environmental movement in western countries stemmed from a desire to protect endangered animal species and natural habitats. Rachel Carson's 'Silent Spring' [4], Brundtland Commission's 'Our Common Future' or William Mc Donough's 'Cradle to Cradle' [5], the approach is similar—parts of a product at its expiry converts to become the sources for new products. These visions and theories have advocated sustainability in the cultural ecosystem of design.

In India, however, it started out as an imperative for human survival [6]. Ramachandra Guha's comment, 'Age of Ecological Arrogance', is very much visible in the practices of production and consumption. Gurugram (Gurgaon) a satellite city of New Delhi is a visible example of this 'ecological arrogance' where the foothills and jungles of Aravalli mountain range and farms on alluvial soil were erased for a new urbanization dominated by the 'impatient capitalist' [7] approach. According to Guha, the three strands representing ideological plurality in the environmental movement in India include Crusading Gandhian, Appropriate Technology, and Ecological Marxists. Crusading Gandhians disseminated an alternative, non-modern philosophy whose roots lay in Indian traditions; the Appropriate Technology tried to validate in practice a set of technological and social alternatives to the prevailing models of development; and, Ecological Marxists embraced environmentalism through conventional political philosophies, notably Marxism [8].

3 Making, Craft, and Historicity

Our physical environment is made of cultural objects that we consume, engage and inhabit, all in the process of our daily actions. Most human activities create relational constructs between cultural objects and its spatial manifestations. These objects at multiple scales belong to a larger cycle of consumption, be it food, textiles, products, buildings or cities. Closing the loop of the cycle is critical from an environmental and energy viewpoint. If we start from the beginning, the *'Making'* of each object ties intrinsically to its causality and effects. Borrowing from chaos theory, there is always a sensitive dependence on initial conditions. Any small change in the causality process and in the initial state can result in large differences in a later state. Most events in space and time related to a cultural object are non-deterministic. However, based on its historicity, cultural relationship and craft (both its material and anthropological dimensions) we can always orchestrate a better physical environment. Inherently looking at an object's making through the lens of its craft and historicity helps create holistic systems addressing multiple dimensions - social, cultural, anthropological, economical, and environmental. The systemic repercussions of forces to make physical cultural objects in a social and environmental context can influence how a community, city, or country functions. Holistic understanding of making, craft, and historicity would help us in formulating a framework for those forces to co-exist.

'*Craft*' defined as an activity involving skill in making things by human labor intrinsically relates to the collective intelligence of societies. Traditionally skills are acquired and knowledge is transferred in an informal way. The transmission is only by the act of making where teachings and directives are oral. The idea of the local with its inherent materiality, constraints, and possibilities is of critical significance in craft. Similarly the close interdependence between 'people' and 'place' with its intrinsic environment, geography and history nurtures an empirical understanding of all cultural objects and their constituents.

'*History*' etymologically speaking means 'knowledge from inquiry'. In essence it is a study of the past as it relates to humans. It is 'his' (human's) 'story', a narrative of relationships. Human relationship to events of the past also relate to any specific objects causality and effects since inception. It is a highly social, cultural and anthropological interweave. Historicity relates to the 'continuity' of traditions, and 'continuity' in Hindi literally translates to 'sustainability' as used in the modern context. Re-appropriation and reinterpretation of historical events as associated with the making of an object creates possibilities for an integrated and inclusive approach.

4 Cultural Design Practices

The primitive human evolved while seeking their primal needs of food, clothing and shelter. In order to realize these an imperative cultural medium were the tools—to hunt and harvest, weave and stitch, or carve and assemble. Modern manifestations of the primitive tools are products. In conjunction with the evolution of agriculture human society transitioned from a predominantly nomadic group to more permanent settlements rooted to a place creating the concept of community and later an urban agglomeration. The research discusses five streams of cultural design practices to explore the meaning of holistic socio-environmental design in post-colonial Indian context. These design practices deal with physical cultural entities be it food, textile, products, building or urban centers.

Historically, Food, Clothing and Shelter have been a political subject in democracy as constitutional promise and a common man's quest, and directly correlate to modern streams of design as Food Design, Textile Design, and Architecture. Product Design forms an integral aspect of contemporary life physiology. Together these necessities are situated in the broader context of the community. The case studies delineating the five design practices embrace all aspects and scales of material based cultural objects.

4.1 Food Design: Cycle and Systems

Designing a food system has the possibility of addressing larger problems of food crisis and malnutrition especially in economically deprived sections of society in the developing world. It also helps in empowering and protecting interests of farmers, workers, and communities directly associated with the food cycle. Food Design is not just to be seen in its immediate sense of visual designing of configurations or enhancing presentation aesthetics or packaging. It is about considering it as a system through the act of making a food product and exploring associated meanings. The process also includes industrial production and distribution networks.

The case presented here is of a popular Indian snack 'papad' (round wafer or flatbread). Traditionally, papad has been a lunch snack of an Indian meal. Shri Mahila Griha Udyog Lijjat Papad, or simply Lijjat, a Non-Governmental Organisation (NGO) has been working through, along with women at home, as a chain of small-scale industries [9]. This organization started in the 1950s with seven women meeting at a rooftop in Southern Mumbai. Though they started with a small borrowed sum, soon they became financially self-reliant and self-sustainable. In 2009, the group consisted of 45,000 women across Mumbai. For many women, the organization and the act of making 'papad' is more than just a daily job; it is an act of leveraging the gap between their poverty and future aspirations. The system has included many more small-scale women working groups and has provided them equal partnership of profits. Currently, the one billion dollar business system has diversified itself in the Fast Moving Consumer Goods (FMCG) market with many more products like wheat flour, spices, and detergent, but the core value of women empowerment has remained the same. To facilitate the system of food design and distribution, the network has still not accepted the use of machines to create their crafted products due to two reasons they believe in: first to avoid the reduction of women labor and consequently jobs, and second to retain the richness in taste and form created by hand.

The practice of food design by Lijjat exhibits a greater commitment to society. Not just economic, but also through social commitment, fair trade, and good ethics. The design, employment, production, and distribution system has reflected and extended on Gandhian ethos of decentralization, self-reliance, Sarvodaya, and critical industrialization along with much needed focus on women empowerment. These practices provide a contextual perspective to the idea of a sustainable system.

4.2 Textile Design: Khadi and Charkha

Historically, one of the first notions in India (and the subcontinent) about Khadi, hand-spun and hand-woven cotton cloth [10], is its stature as the symbol of the independence movement. In ancient societies hand-spun and hand-woven cotton were also used as barter. In the Indian independence movement, Khadi was portrayed as not just a homegrown fabric but also as an ideology of self-reliance and self-sufficiency to counter the import of mill-made English shirts. Interestingly these shirts were made out of exported Indian cotton. Used in the national flag as well as in the attire of independence movement protagonists, the nationalistic affinity still resonates.

The existence of Khadi is beyond its tactile feeling. A holistic life cycle analysis suggests how this organic material is sustainable environmentally and socially. It is soft on ecology as it is totally decomposable. Use of Khadi by Buddhist monks is a good example of its material life. It starts from being a robe cloth to a modest carpet to an altruistic wick in the lamps. Socially, in its production, most of the artisans and craftsmen from small-scale handloom industries are associated with it. Primarily this practice supports the economy at the bottom of the pyramid. Since most of its weavers and craftsmen are from rural parts of the country, a charkha (spinning wheel) or a basic handloom can be installed with a small capital. The natural dyes and colors it uses towards finishing again supports the agrarian economy assisting farmers.

Beyond a tangible product produced from Charkha, Khadi was seen in connection with Gandhi's New Education. Gandhi advocated if every citizen in the country spun Khadi, it would have brought an equity and social justice in the society. Post-independence, to promote Khadi, the Government of India established the Khadi and Village Industries Commission (KVIC). It has been presenting this fabric to consumers through a chain of showrooms and shops in most Indian cities.

At the academic level there have been scholarships to experiment with the material and its design through cluster documentation projects at National Institute of Fashion Technology and National Institute of Design. Contemporary fashion labels like Fabindia and designers Rohit Bal and Ritu Kumar have contributed in its promotion. However, Ravish Kumar's recent documentary [11] laments on the apologetic state of Khadi. With no chronic exploitation of human or natural resources, Khadi can be seen as a way forward in creating a Green Economy [10]. This is one of the reasons Gandhi saw it is as a tool to eradicate poverty in India. In contemporary India one can see its potential contribution towards ecological, economic, socio-cultural and historical (as a symbol) sustainability.

4.3 Product Design: Craft

Tools are currently interpreted as objects that aid in making products. However tools themselves are products. Contemporary interpretation of products can be seen through the translation of what tools used to be in primitive societies. Out of all the craft traditions in India, bamboo has the potential to replace unsustainable materials of the present design culture. With over 13 million bamboo craftsmen in India, it becomes more relevant than ever. Being a renewable, re-generable, fast growing and eco-friendly material, it becomes not just the material of the present, but also of the future. While there have been many initiatives by various governmental organizations, two initiatives at the design pedagogy level have greatly influenced designers in India in their contemporary experiments.

One of the first initiatives in the revival of bamboo craft at practice and pedagogical level is by Prof. A.G. Rao, who established the Bamboo Studio at IDC, IIT Bombay. One of the major contributions of this studio along with sponsorship from UNDP and Ministry of Textiles of the Government of India has been the development of a tool kit to work with bamboo as a material from cutting to final finishing. It has facilitated not just craftsmen but many contemporary designers to think and work with bamboo.

The second initiative can be seen in the efforts of Late Prof. M.P. Ranjan at National Institute of Design, Ahmedabad. He orchestrated an extensive study [12] through Centre for Bamboo Initiatives in northeastern India and collaborated with local craftsmen to come up with contemporary design. Through the project, designers and students at NID Ahmedabad learnt a traditional craft; at the same time it empowered and provided exposure to the rural craft community [13]. Patel [14] has mentioned that bamboo's absence from international design fairs and festivals has omitted it from mainstream design literature. One can see greater values of critical industrialization, welfare for craftsmen, and village empowerment. It is essential to highlight bamboo in Indian Design History and revive the tradition. One can relate with the sustainable idea of promoting handicrafts and naturally made objects with minimum industrialization to assure a sustainable future.

4.4 Building Design: Material, Craft and Local

Houses built by primitive people differ widely, being completely dependent upon the type of "cutting tool" (technique and craft) and "landscape" (climate and material) in which they live [15]. The concept of the vernacular in India in terms of building materials refers to the indigenous rural systems existing for centuries. Traditionally the surrounding country provides building materials - timber, bamboo and thatch in humid tropics; stone, earth and bricks for arid zones; and mixture of organic and inorganic materials for composite climates [16].

Contrary to popular belief of being a pre-dominantly hot tropical country, India has varied Koppen climate zones with diverse geographies and ethnic groups. Each geography and climate has local building material systems that have developed over centuries. From the Kath-Khuni houses of Himachal Pradesh with its stone-wood construction that is earthquake resistant and protective from extreme Himalayan cold weather, to the *havelis* of Rajasthan that uses textures and self-shading at multiple scales to respond to the hot desert climate, to the courtyard houses of Kerala with its own social evolution and response to the humid monsoon climate, are all examples that validate socio-environmental design in Indian Vernacular. The widespread practice is to build using services of traditional artisans who acquire their skills under a loosely organized system of craft apprenticeship. The construction techniques have grown out of locally available materials and constraints. The close interdependence between people and place fosters an empirical understanding of construction material and its quality, seasonal changes in temperature and humidity, need based sizes of various spaces, tools and technology, all of which are reflected in traditional building techniques [17].

In mainstream architecture, very few practitioners have worked in the socio-environmental context. The 'trophy' buildings in post-liberal additions to Indian cities (like Gurgaon) are perfect examples of sustainability being objectified and abused by 'green' accreditors. Post-independent India adapted Nehruvian form of concrete modernism over Gandhian form of vernacular and earthy evolution [18]. The former was justified through a projected need of creating an identity among the emerging powers of the world. However, the timelines of Gandhi-Nehru debate was stolen by 'impatient capitalist' forces [7], which bargained nothing, but a glass façade based globalization to project a modern India in the new IT enabled century. From the Indian post-modern architecture, Kenneth Frampton has classified the works of Correa within the category of Critical Regionalism [19]. Bijoy Jain (Studio Mumbai) too has developed a contextual aesthetic sensibility through well-crafted residences and weekend homes designed in tandem with craftsmen and artisans using local materials with contemporary taste. He has established the notion of the architect as a master mason working closely with allied artisans. However, the social impact of such projects can be contested.

The western theorists within the canon of modernism have missed or ignored alternate ecologically grounded practices. Laurie Baker is one such architect with an alternate practice. Baker came to India as a volunteer and later settled. Along with his faith as a Quaker, it was a brief meeting with Gandhi that influenced his work in India [20]. He is one of the few that challenged the status quo and tried educating and involving the decision makers including the politicians. His collaborative COSTFORD's mission is to work, promote and propagate alternative technologies for civil and architectural construction in towns and villages. His residence, the hamlet, is the manifestation of his character, principles and architectural beliefs [18]. The construction process illustrates the traditional and natural way towards habitation and development. The source of most of the construction material came from various unconventional sources like roofing wood from a dilapidated house, wood from a jetty, and pieces of stone or tile, which all juxtapose in harmony [18]. Another example of Baker's empathy towards society and environment is the design of Chengalchoola, a slum redevelopment project. The challenge was to keep it low-cost, which is often interpreted as making repetative units killing the vibrant social fabric. Functionally, the houses at Chengalchoola are efficient, well lit and ventilated. The shared open space provides the opportunity for cultural sustainance. Baker provided a unique character of spatial diversity within the unity of materials. His wide variety of works dealt with not so common 'common sense'.

4.5 Urban Design: Community (Villages, Towns and Cities)

With the evolution of agriculture—domestication of vegetation together with irrigation, human society transitioned from a predominantly nomadic group of hunters to more permanent settlements. It established communities that were rooted to a place. Such transitions happened in parallel across the globe, which eventually over periods of time led to the formation of major world civilizations, leading to the concept of an urban agglomeration. In India, medieval invasions from modern day Turkey, Iran, and Afghanistan, and later British colonialism developed new cultures, which integrated with the existing, creating new identities. Modern Indian cities are a reflection in time of different urban practices, social customs and forms of governance. Through a historical narrative one can situate the pluralistic urban condition that India is associated with. The urban diversity is produced as a layering process of its cultures and sub-cultures, geographies, religions, ethnicities, climate, and materiality. Urban precedents serving as models for future development are regional and at times sub-regional. Response to climate along with a distinctive geography, ethnicity, and history has created diverse urban forms. The urban fabric of the city reflects the material geography of the region within a social and environmental dimension.

In post independent India Auroville serves as a good urban precedent. Founded in 1968 by "The Mother" Mirra Alfassa, spiritual collaborator of Sri Aurobindo and designed by architect Roger Anger [21], Auroville was envisioned as a utopian community. Mirra Alfassa believed that such a universal township would contribute decisively to the Indian renaissance. It was based on the philosophy of Sri

Aurobindo. As a contemporary neo-liberal community, Auroville encouraged integral living and developed a platform for experimental architecture.

Through the 'Smart City' initiative we are discussing cities for the first time in India. The relevance of 'smart' and associated technologies in the Indian context can be contentious but it is definitely an opportunity to provide for basic physical infrastructure. Development guidelines should incorporate dimensions of society and demographics, environment and materials, governance and community participation, seen through the lens of history and continuity rather than paradigms started from scratch and completed as finished constructs.

5 Conclusion

Verbeek and Kockelkoren [22] argue that traditional lifecycle analysis leaves the fundamental problem of sustainability unaddressed. When designers discuss objects, they almost always talk about them in terms of signs, function, meaning, or styles. We argue, focusing on an object's making, craft, and historicity creates possibilities of an integrated and inclusive approach to discover holistic dimensions of socio-environmental design. In his recent work, Thackara [23] also demonstrates the best case studies from the world through the bare necessities and modern man's daily encounters with life as: Changing, Grounding, Waterkeeping, Dwelling, Feeding, Clothing, Moving, Caring, Commoning and Knowing. Through his themes, Thackara has attempted to present all stakeholders a holistic and entangled vision of sustainability. Similarly, the objective of the cases presented here is to demonstrate the systemic repercussions of physical cultural objects in a social and environmental context, which can influence the functions of a community, city, or country. And that be attained through a holistic understanding of making, craft, and historicity of objects.

It is critical to introspect for a culturally rooted future. Throughout the political history of India, one can see tones of future-focused thinking at the top of institutional pyramid. However most of the thinking ends up in policies driven by technology (as an end and not as a means) completely ignoring the cultural, social, environmental, and anthropological dimension. The most appropriate example is that of the current aggressive call for 100 'Smart Cities' by current Indian Prime Minister Narendra Modi, where the notion of smart city has been showcased and sold as a technology branding exercise. The greatest missing links in the conversation about smart cities are people, culture and housing. The contracts have been awarded to western technology giants operating as Technology and Software Consultancies who possess the infrastructure and resources to carry out the operation, but completely lack in experience to operate in a cultural context. The concept portrayed is that of the city as a 'company' and an absolute technological product. However, a city is a work in progress; a cultural artifact that thrives in contestation and negotiation of its people. The same logic trickles down to products of multiple scales as discussed in above sections.

The present context of India is dominated by social paroxysms, cultural ambiguities, economic reorientations and environmental adjustments. Globalization challenges many notions of post-independence identity. Unprecedented migration amongst other phenomena redefines concepts of global and local, far and near, theirs and ours [24]. In such a pluralistic setting, the specificity and historicity of context is significant to develop culturally appropriate and environmentally responsive designs. The idea of the local in a constantly globalized world is to be assessed. Local materials and craft not only ensure low embodied energy of objects (Environmental), it activates working communities (Social) and improves local economy (Economical). To conclude, one can say there is a need to harness traditional crafts, building methods, and organic logic of development of villages, and to consume local materials, food, and daily objects. These evolved systems already in place in traditional societies are the collective intelligence of generations. Some may be out of context in globalized contemporary Indian cities but there is a need to reinterpret and re-appropriate them. The discussion above creates a framework across multiple scales of food, textiles, products, buildings, and cities following a singular inclusive and holistic socio-environmental approach seen through the lens of contemporary culture. While there are design forces chasing modernity and strictly consumerist culture, an inclusive tradition of Social Design can be practiced. These practices are examples of cultural design visions from India rooted in making, craft, and historicity.

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Design for Innovation: Toys for Sustainable Play

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Abstract In this paper, we estimate the impact of alternative materials and manufacturing when designing toys considering both the impact on children health and on the environment. In order to achieve this goal, we have proposed to design a geometric box set that can be 3D printed with a material prepared with beetroot puree. Although the results have showed it is possible to obtain functional properties using alternative greener materials manufactured with additive prototyping machines, it was expected that the impact on the environment could be more significant. In other words, in addition to innovation in materials, which in this case end up providing a safer product for children, much more need to be done in other steps of the design and production chain in order to reduce gas emissions.

Keywords Toys design · Sustainable materials · 3D printing · Children safety

1 Introduction

The purpose of this study is to identify safer and environmental friendly materials for toys design. Recently, kids' advocates have been paying more attention to these issues given that children, whose immune system is more susceptible, might be exposed to hazardous substances. They are at risk of developing diseases such as seen in some birth defects, cancers, and autism, that some researches claim to be related to environmental contaminants [2]. Therefore, regulators

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such as the European Union Toy Safety Directive and the US Consumer Product Safety Commission have addressed numerous perils that have been identified with toys, including strict limits on what types of materials can be used in toys [1–4].

At the same time, toys industry should be able to improve energy efficiency, minimize greenhouse gas (GHG) emissions, conserve water, and to reduce the amount of waste it generates, and then reuse any waste material where possible, recycling almost everything that is left. Also, children would learn at an early age the importance of protecting the environment.

In order to get further understand of these problems, we have proposed to analyze functionality and the environmental impact of a non-toxic polymer, made with natural ingredients [5].

As a conceptual demonstration, we designed a geometric box set that can be realized in physical form with Additive Manufacturing. In addition to reduce the distance between digital design and the building of physical prototypes, tested if the material is viable for 3D printing [6, 7]. In this case, it has to attend three different requisites:

(i) initial extrusion into plastic filament;
(ii) extrusion and trace-binding during the 3D printing process;
(iii) end use application;
(iv) environmental impact;

The remainder of this paper was divided into the following sections: (2) a brief review of the importance of toys for children development, and the key role played by materials selection and 3D printing as a source of innovative design; (3) describes the methodological approach; (4) presents the results, while (5) concludes pointing for future directions.

2 The Past and the Future of Toys

2.1 Playing in the Antiquity

According to Crawford [8], playing has been a fundamental aspect of children development across cultures and species. Psychologists have shown that, in addition to be fun, imaginative play is important for achieving high-level skills as decision-making, socialization, and creativity.

Ever since the antiquity, toys have been used by children as form of entertainment and learning. There are historical evidences that dolls have been produced about 40,000 years. In India, dolls and toys were not only to play, but had ritual significance. The sane was found in Ancient Egypt, after archaeological discover of dolls in children tombs dating back 2000–3000 years BC. A curiosity is that, according to researchers, children and toys were placed together so they could play after death [9].

It is well accepted the idea that building toys and playing games are part of children discover of the world. One of this experience is the interaction with the material environment [10]. Toys were made of wood and plated with clay. The best-researched indigenous betting game in the central Andes involved tossing into the air a pyramid-shaped dice made of bone, wood or stone. Balls also have been found dating from 6000 to 500 years ago. In Japan, they were produced with bamboo fibers while in China with animals' furs.

2.2 *Toys Made with Eco-materials and 3D Printed*

With the advancement of new technologies, the future of play continues to evolve [11, 12]. Current trends in toy design focus on 3D sustainable materials printing and, opening up a new world of potential business opportunities. Another trend in this market is that, according to The Guardian, these days parents have become more concerned about the impact of toys on their children health as well as on the environment. Therefore, they have taken the same care as they do when choosing food [13].

Therefore, nowadays, as important as considering functional characteristics during material selection, it is also mandatory to focus on their ingredients to calculate the impact on human and environmental health [14]. Figure 1 depicts materials in terms of major categorization based it is a natural or man-made source.

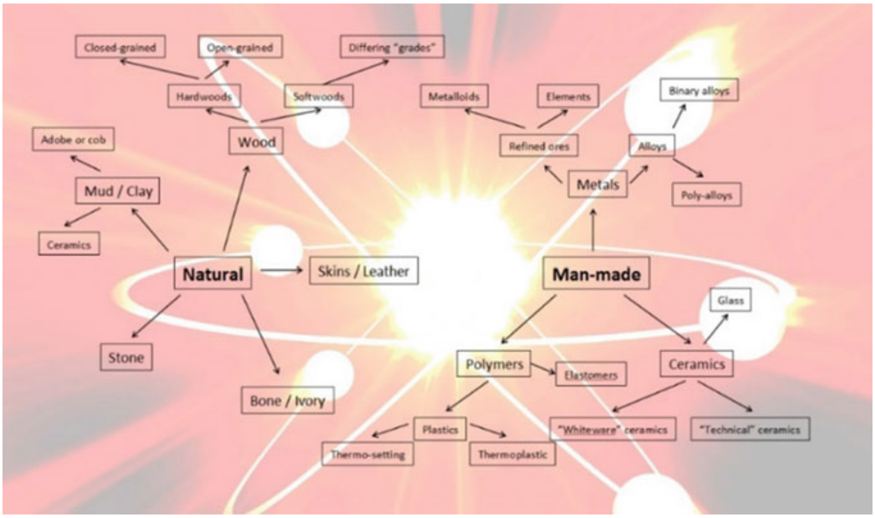


Fig. 1 Classification and structure of materials. *Source* 15

The use of innovative materials has also transformed the business model in toy industry. In the US, startups such as Luke's Toy Factory, design its toys using recycled, organic materials. Its toys are made of a wood-plastic composite, which has contributed to decreasing the use of plastic in their toys in less than 40% when compared to similar ones [16].

Although many attention has been paid to materials, it is equally important to understand about manufacturing process. Additive Manufacturing, 3D Printing or Rapid Prototyping are all synonyms for the process wherein a solid three-dimensional object is printed layer by layer from raw material. Since many toys are small and made out of plastic, it is faster and cheaper to manufacturing them with 3D printing.

3 Research Design

3.1 Materials

In this research, we have chosen Embrapa methods for preparing natural materials. For this experiment, we have prepared a dough made of beetroot puree. More explanations on the material preparation can be seem in Lovecie et al. [17].

3.1.1 Ingredients

Quantities used to produce 32–35 g of beetroot dough.

Citrus Pectin 6–7%.

Beetroot in natura 25% (relative to the mass of pectin):

400 g water
28.06 g Citrus Pectin
9.36 g beet beet puree

3.1.2 Processing

The components should be mixed for 10 min in a Turak type mixer 12,000 rpm.

The material features a low-cost with high-performance rheological properties prepared and cured at Temperature 120 °C (drying chamber length = 80 cm). The carbohydrate-based composite, once ready, is a smooth paste with uniform consistency and its wet blade thickness is 1 mm while stretching speed is 12 cm/min (Fig. 2).

Fig. 2 Beetroot dough. *Source* Authors

3.2 Design and Fabrication

For design, we have used SolidWorks 2012, a three-dimensional modelling software that is user friendly, and affordable for the completion of this task. It is a tool that helps to conceptualize and optimize product functionality and innovation in the early stages of design and engineering process. In addition, it is also possible to endorse the product according to design choices as well as its impact on manufacturing.

For the fabrication of the designed parts, we used the FLEX3DM-V10, is a 3D printer totally designed and developed by Prof Lira's research group. The FLEX3DM-V10 is a modular, open-design, and multi-material printer. It is called flexible because it has three interchangeable devices such as:

i. an injection molding for processing materials in room temperature;
ii. the tool for polymer extrusion process;
iii. The drill for boring and milling.

Figure 3 shows the extruder device in realistic view and a picture of FLEX3DM-V10 in the lab. The deposite material is spread in X and Y directions according to a tool path such that it processes build the prototype with efficiency and geometrical accuracy.

4 The Impact of Toys Design on Environment

4.1 Geometric Box Set

The first part of this experiment consisted of sketching a geometric solid box set to build a 3D model. Then we used SolidWorks to design the shapes necessary for printing it. After this process, we could obtain the physical parts of the box (Fig. 4).

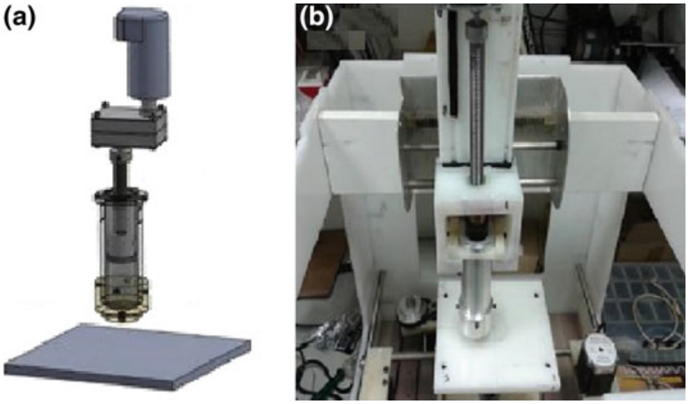
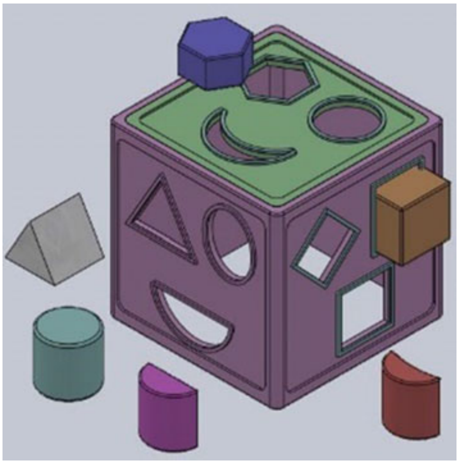


Fig. 3 3D view of extruder (**a**) Picture FLEX3DM-V10 (**b**). *Source* Authors

Fig. 4 Geometric box set. *Source* Authors



4.2 The Making of Beetroot Dough for Protoparts Printing

Knowledge of the adhesion between the layers was obtained by depositing the material in layers, one over the other. The layer thickness is the same as extruder nozzle and its cure time was 24 h in a 25 °C room temperature. In Fig. 5, we can see the uniformity of the extruded composite filaments.

Fig. 5 Extruded filaments. *Source* Authors

After curing of the layers, it was found that the adhesion between them is appropriated to construct the designed box. However, it was necessary to do some adjustments both in the extruder device and in the consistency of the paste.

4.3 Estimating the Environmental Impact on the Beetroot Dough Processing and the Toy Prototyping

The toy production process consists of the production of a dough made of beetroot puree and the toy additive manufacturing presented in the previous section. The estimation of environmental impacts was conducted in two parts using SolidWorks Sustainability 2012. First we estimated the environmental impacts of processing the beetroot dough and then the environmental impacts of toys manufacturing. In our analysis, we considered the production of 1 m^3 of beetroot for the volume of 1 m^3 of toy produced.

SolidWorks Sustainability provides four parameters that underpin the final estimate of the sustainability of toys life cycle. They are part of the emissions that results of the process. Basically, they are.

Carbon Footprint—Carbon Dioxide (CO_2)
Air Acidification—Sulfur Dioxide (SO_2)
Eutrophication of Water—Phosphate (PO_4)
Energy Consumption

To calculate the environmental impact, we need estimate data about geographical location; percentage and type of energy used, transport and distances traveled and percentage allocation at the end of its useful life of recycling, incineration and disposal in landfill. These estimates were considered the values shown in Table 1.

At the same time, we need to estimate the environmental impact on beetroot dough considered the physical properties of the puree produced according to data and values given in Table 2.

Table 1 Parameters used for estimating environmental impact

Geographic location	South America
Road transport	200 km
Life cycle	1 year
Recycling	18%
Incineration	2%
Final disposable	80%

Table 2 Physical properties of beetroot puree

Density	1150 kg/m^3
Thermal conductivity	0.52 W/(mK)
Specific heat	3460 J/(kgK)

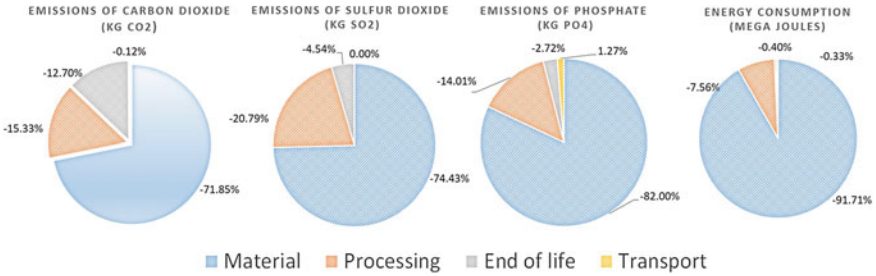


Fig. 6 Beetroot dough emissions. *Source* Authors

In Fig. 6, we can see the percentages of Carbon Dioxide, Sulfur Dioxide, Phosphate Emissions and Energy Consumption demanded by the processing of beetroot dough.

The percentage of emissions of carbon dioxide, sulfur dioxide, phosphate emissions and energy consumption both in the beetroot dough processing as well as the toy manufacturing are significantly higher due to the processing of basic materials, in this case citrus pectin, beetroots and water needed to prepare the main component.

The production of citrus pectin considers the path that goes from the harvest of orange, which is mechanized, its transportation, which is almost the entire way to the processing steps to the beetroot dough manufacturing facility. This process overlapping environmental impacts also occurs with the beet, which also depends on mechanical harvesting, which transportation is around 250 km distant from urban centers. Likewise, the water employed in the beetroot dough undergo through a system of treatment and distribution in a distance of approximately 200 km.

Once the beetroot dough components are available, the mass production processing of beetroots is relatively simple and fast. First of all, it is necessary to mix the components in the proportions indicated in the Sect. 3.1.1 for 10 min. After a

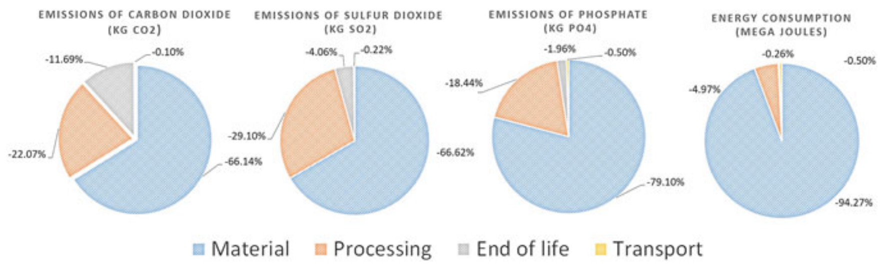


Fig. 7 Toys manufacturing emissions. *Source* Authors

period of rest the material is ready for use. Therefore, the impact of the beetroot dough processing is lesser if compared to the impact of the process of each material component. Finally, the impacts on the end of the beetroot lifecycle is based on the percentage assigned as the share at the end of its useful lifecycle can be recycled, incinerated and disposed in landfill.

The environmental impacts of 3D printing are not the same than the impacts of the real manufacturing process. In Fig. 7 we can estimate that although there is a decrease in the percentage of the material impact on the environment, this is followed by an increase in percentage on the production process. These variations are due to energy consumption by prototyping machine.

Numbers indicate that, although there are only 2.6% more in electricity consumption, environmental impacts can reach 8.3% more as in the case of phosphate emissions. In addition, it is considered that there is no demand for local transport material to mass production with prototyping machine, which results in lower environmental impact. The change of 1% in relation to the item end of lifecycle emissions of carbon dioxide can be considered insignificant.

The results of such experiments, as seen in Figs. 6 and 7, demonstrate that, as we reduce the amount of material production, only the materials and processing have significant impact on environment.

5 Conclusions and Recommendations for Future Research

In this article we could see that designers have an important contribution when creating products for children. It is necessary now to carefully understand the properties of materials that go beyond the technical and economic one. Now designers need to understand that materials have a strong impact on children health.

Considering that three-dimensional printing has come to speed the time to market of tangible goods, consequently life cycle of toys are going to get much shorter. As a result, we are going to presence an increase of carbon footprint.

A solution for this problem is that to ally the rapid prototyping machine, which, for been faster, does not consume the amount of energy used in traditional process, we suggest the use of natural materials to make up for energy consumption. As the environmental analysis showed, material made of natural composite such as vegetables and fruits seems to be safer for toys. First of all, they have both physical and chemical properties used in food related products. They are also biodegradable and sustainable. At the same time, vegetables may be a source of color, flavor, and even nutritional properties.

Finally, designers should also be aware about socioeconomic impacts when making a choice. Some sustainable materials are made of a variety of organic material such as fruits, crops, milk. As showed in the 2008 food crisis, we have to pay attention to the dilemma of switching the use of the land used for food production or crops to other applications given it can have a great impact on food system security due to changes on food supply and demand [18, 19].

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A Story of Languishing Doll: Revival of Cloth Dolls of India

Satyendra Kumar Mishra and Satyaki Roy

Abstract India has very rich culture of crafts from ancient time, crafts have always been fascinating for human being. Handicrafts have been source of creative self expression, cultural stability and livelihood. Before industrialization, dolls act as an ambassador's of culture, reflecting 5000 years of old tradition. The existence of cloth doll has been as old as cloth itself. In India cloth dolls were one of the most popular craft during 1950s, where almost every second house was practicing this craft, at the time of industrialization, mechanization of every industry was preference everywhere. In result to industrialization, current scenario reflects the picture where cloth doll of India has fallen in the category of languishing crafts. The aim of this research is to find out the reasons of extinction of cloth doll and to explore some of the factors that could led craft revival and restoration in present scenario.

Keywords Cloth doll making · Languishing craft · Revival · Designs avenues

1 Introduction

The history of cloth dolls are as old as mankind, since prehistoric times, earliest existing cloth dolls were found preserved in wealthy patrons of ancient Egyptian tombs, which was used to depict religious figures or as playthings, probably the primitive dolls were made out of materials like clay, fur and wood. Dolls might have survived before prehistoric period, although a fragment of an Alabaster doll with movable arms were found from the Babylonian period.

Cave men artist carved the first doll 'Adam' around 30,000 years ago, Walter Hough, noted Anthropologist of United States National Museum, mentioned the

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ancestry of smiling unbreakable doll of the modern toy shop has now been carried back generations beyond the oldest dolls, loved by Greek and Egyptian children, back into prehistoric times.

The history of prehistoric dolls from childish toy into the mysterious cult, where dolls were worshiped as an idol or an object for witch craft. The prehistoric dolls were as different from modern dolls as prehistoric men were different from modern men. Among primitive children, feeling of fear associated with supernatural things, they would not play with dolls at all rather crooning over a long rock tied up in a bit of reindeer skin.

The oldest carved doll image were small female figure, date back to the Aurignac ion period of the old stone age and they were known as stone age Venuses, the oldest of them, perhaps is a female figure found at Brassempouy in France.

Terracotta dolls with movable heads were found at the site of Indus Valley and Harappa civilization (2500 BC), usage of these dolls were very common in ritualistic occasions, these human and animal figures predates the Vedic Aryan culture.

Dolls which were found in Egyptian graves dating back to 2000 BC were mainly made up of clay or wood, painted with various designs, hair made up of strings of clay or wooden beads. Dolls places in these graves leads some to believe that they were cherished possessions.

Dolls were also buried in Greek and Roman children's graves. Grown up girls from Greece and Rome dedicated their dolls to goddesses. Most of the dolls, which were found in Children's graves were very primitive in features, often made up of wood, clay, rugs or bone. Some of them were very unique made with ivory and wax.

1.1 Dolls of India

The sensibility of creating shapes and figures with stone have been found at Neolithic sites (C. 7500–3500 B.C.), [1], more complex uncovered toys were found among the remains of Indus Valley civilisation, (C. 2500–1700 B.C.). The remains give an impression that, different body parts of these toys were made separately and joined together with a string. Over a period of time many materials evolved and invention of cloth brought a remarkable change in the area of doll making, the material gave a liberty to an artisans to explore with an interesting shapes and forms.

In Indian history from ancient time to modern is recounted in a series of dolls. The simple folk of India find a place in beautiful cloth dolls that project ritualistic life of Indians. The vividly colorful Indian dances like *Kathakali*, *Bhangra*, *Manipuri*, *Kuchipudi* etc. its vigor and exuberance are also very well depicted through dolls (Fig. 1).

The above visual showcase of Indian Folk Toys [1], where materials used are (Clockwise from top left): Clay, wood, metal, cloth, cloth and paper. The Venuses of stone age evolved with time and slowly took shape with many different material, but fabric was one of the material which shaped it into a glamorous figure, where children as well as every human being could find a relationship with themselves.

Fig. 1 Folk toys of India (*Source* [1])

Indians always had very special affection for cloth dolls, It was part of their tradition, Indians have grown up with it. At one point of time, dolls were given away as a wedding presents to the child bride. Dolls, not only provide a diversion but also a colorful canvas for depicting Indian life in its plethora of cultural beauties.

The puppeteers from Northern India, specially from Rajasthan believes that dolls are sacred objects, when these dolls are broken or beyond repair, they are not simply thrown away, rather they are float down in sacred rivers of India.

Orr [2], "Puppets dolls are popular in south India, and existed in India from about the time of Christ". Marionettes were very popular with Nomadic Gypsies, whose ancestral homes was Northwest and North Central India. The materials used to modeled these dolls were mainly wood, paper Mache, leather and cloth. Most of the time these dolls were developed with used clothes, the body of the dolls were made of white dhoti (Indian male attire), and the clothing's are of sari (India female attire). Dolls from different state are representatives of their states, clothing's are mainly inspired from local traditional style of attire. Puppet doll performances in the village of Rajasthan and south India were one of the main sources of entertainments, it was performed during different occasions like marriages, as well as births and funerals, these performances were also performed during religious occasions. Puppet doll performances are considered auspicious by the village folks [3].

In India, around 1950s every alternate household was involved in making cloth dolls, many different clusters were also dependent for their livelihood by doll making [4]. Around 1956, Upendra Maharathi (Craft Revivalist) set up a craft

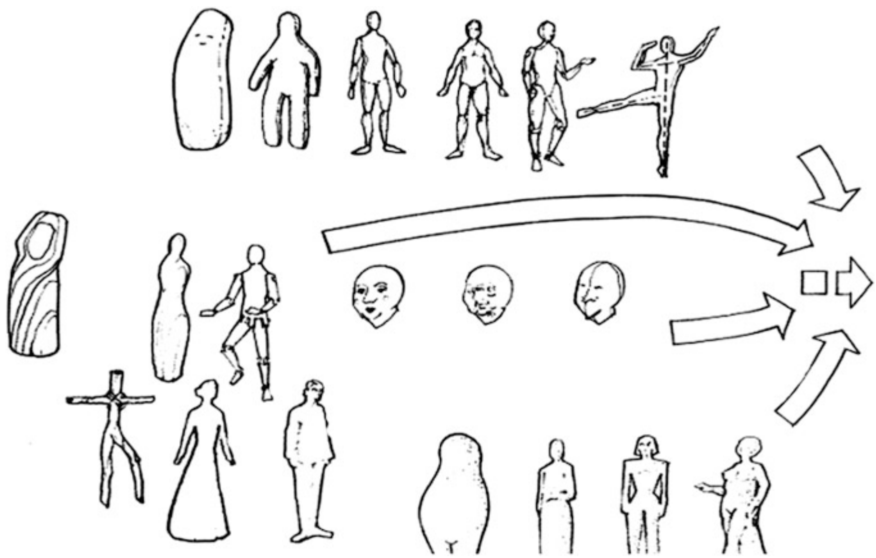

Fig. 2 Gradual change in forms over time (*Source* Susanna Oroyan, Anatomy of a Doll, p. 12)

research Institute at Patna, Bihar in collaboration with Government. In this Institute, cloth doll making was one of the most emphasized craft, where planning was to develop it, as a craft cultural identity of Bihar state, India. With time, after the loss of Upendra Maharathi, due to ignorance of Government and effect of industrialization in every sector, these dolls started vanishing from the map of India (Fig. 2).

1.2 Evolution of Doll's Body Form

From centuries, cloth dolls were made by mothers for their children, it is generically refer to dolls made up of fabrics. Cloth dolls refers to a subset of rug's, dolls made of linen or cotton. Every region of India had its own special type of dolls like *Kathaputali* [5]. Mainly they were famous from the state of Rajasthan, these dolls were used to narrate moral stories.

1.3 Cloth Doll

The invention of fabric, developed an ideation process, an abstract forms gradually started taking shapes and forms of actual human figure, it also gave flexibility to conceptualise and create an aesthetically beautified figures.

1.4 Making Techniques

The conceptualized shapes are drawn on fabric, cut and stitched together as per desirable figure, body is mostly made up of used white, off-white or skin colour cloth. The different body parts are made separately and joint together with the help of thread or wire. These figures are often decorated with intricate and gorgeous dresses. Along with time cloth faces, feet and palms changed into casted Plaster of Paris (POP), the change made figure more defined and presentable (Fig. 3).

1.5 Effect of Industrialisation on Craft

Industrialisation brought a major change in society, thought process of pre—industrial society was inevitably different from industrial society [6]. In order to grow

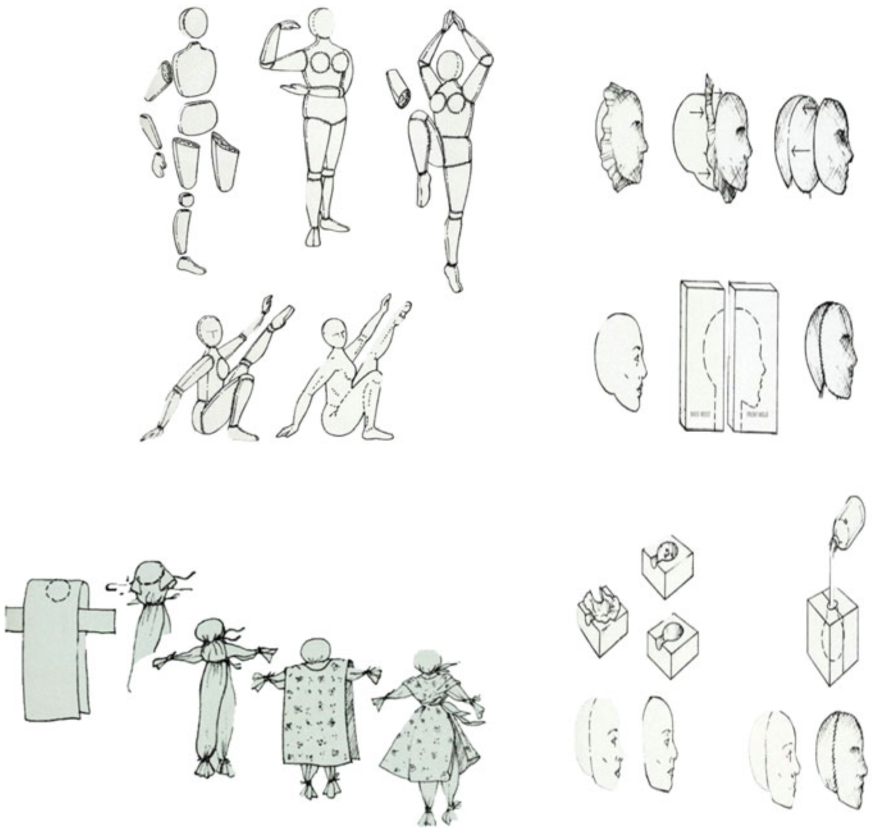

Fig. 3 Creating body shape by Stitching, tying of fabrics and faces of POP (*Source* Susanna Oroyan, Anatomy of a Doll, p. 17 and 53)

faster, countries started losing their cultural identity, new highly productive machineries came into existence, the differences were not only in terms of quantities rather an industrialized community had a very different thought in terms of living and everyday lives. The products developed by machines were much more cost effective and readily available, the concept of mass production shifted the consumers from handmade to machine made. The effect of industrialization could be seen on the crafts like doll making, carpet, glassware, jewelry making, traditional textiles, gems, jute products etc.

"I doubt that the folk toys that I have described will disappear with the spread of industrialisation in India, as has happened in other countries" [1], the doubt of Mohan, has taken shape by now. In doll making cluster of Bihar, India, where more than five thousand of people were associated and earning their livelihood till seventies, disappeared, not even a single person is practicing the craft [7]. The soul of hand crafted dazzling star has moved out in the world made of Iron [8]. Many artisan's families have migrated to metros of India, in search of bread and butter.

1.6 Revival's Tale

In 1907, Anand K. Kumarswamy, actively took part and initiated the production of handicrafts into the nationalist movement, under the guidance of Mahatma Gandhi [9]. he researched extensively in the field of handicrafts, wrote and presented papers for the revival of handicrafts, later many intellectuals like Jamini Roy and K.C.S. Panikar, supported and developed arts and crafts in colonial India.

In the year 1965, establishment of Shankar's International Doll Museum at New Delhi, India, by renowned political cartoonist, K. Shankar Pillai, flashed a spark in the area of reestablishing doll craft in India, initially the concept restrained the dolls within the boundaries of museum, over time the museum gained popularity and many artists and designers drew inspiration for their designs [10].

After Tsunami's devastation on 26th of December'2004, at Indian coast, as a course of healing for fisherwomen, a design studio called "Upasana" at international township Auroville, Pondicherry, came up with the concept of a doll, made up of left over cloths called "Tsunamika", many women from Karnataka, Tamil Nadu and Pondicherry, were trained to develop these small dolls. It has been more than ten years, Tsunamika has generated livelihood for hundreds of families and conquest pains of many traumatized women.

An artist from Mysore, Gujarat, Asha Rashmi, in her interview with Times of India (2011), shares her feelings about her passion of doll making. she says, I do not do it, for the sake of business only, crafting doll is like a prayer for me. Every year, she starts making dolls particularly one month prior to Navaratri (Festival of India, celebrated in the month of October–November). Asha said, more than sixty percent of materials used are recycled old cloths, very few materials are purchased. she also mentions, it is one of the main source of livelihood for her family.

The famous tribal cloth dolls of Jhabua District of Madhya Pradesh, India, was in state of dying in the year 2004, It was given rebirth with help of National Institute of Fashion Technology, New Delhi in collaboration with Government of India under Swarna Jayanti Gram Swarozgar Yojana (A scheme by Ministry of Rural development, Govt. of India).

As per most recent data, handicrafts sector of India has shown a remarkable contribution to Indian economy, these data represent healthy overview of this sector, opposite to this the real heroes "The Artisans" do not correspond to same, a grim picture of handicrafts artisans need real attention of an individual, society and Government of India.

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Smart-Cities for India: Why not *Open-Source* Villages?

Paul Varghese

Abstract This concept paper examines the bases for the 100 *smart-cities* proposed in India—a partial solution is the adoption of leapfrogging technologies. It argues instead for the idea of *smart-villages*, like the *PURA* model proposed by Abdul Kalam, which could build up rural areas and mitigate migration. Better would be a scheme of *open-source* architecture/settlements supported by ICT, developable for rural areas; further, their inherent knowledge needs to be captured, preserved and adapted to today's context.

Keywords Smart-cities · Leapfrogging · E-governance · Smart-villages · Open-source · Traditional knowledge

1 Introduction

Humankind is being thrust headlong into the 21st century, often without options. In parts of the world, human-induced changes of urbanisation, pollution, war, or effects of climate change—deforestation and drought, affect people. Modern technology has come as both a boon and a bane, even in the remotest parts of the world. This is partly because of a significant rise in the global population, 7.5 times in the last 200 years—from an estimated population of a billion in 1804 to 7.43 billion today (08/2016). Much of this followed the Industrial Revolution; new developments in science, medicine and technology gave increased life-spans, falling infant-mortality rates, lesser deaths from hunger, disease and similar. India's 2016 population stands at 1.329 billion with a life expectancy at birth of 68 years, and an infant mortality rate under age five of 47.7 deaths per thousand [1].

Technology has been a global component in making humankind a part of the process disturbing the planet, from what a few centuries ago was at the mercy of

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Nature; today, the human-made world affecting the processes of Nature itself, sufficient to cause an imbalance.

The paper examines how administrative decision-making in the country seems to be without consideration of many aspects, which could affect a section of the population, mainly in the rural areas. Often decisions taken are based on economic and political considerations, but the effects spin off into many other sectors. The justification for developing *smart-cities* based on urban considerations seems biased against those in rural areas. Instead, the paper proposes an equitable distribution of resources which benefit more of the population. It proposes diverse processes, based on an *open-source* system of knowledge sharing, taken from models in the information and communications technologies (ICT) field.

2 Technological Leapfrogging

The late physicist Albert Einstein (1879–1955) said, "*We can't solve problems by using the same kind of thinking we used when we created them*".

2.1 The Indian Scenario

An advantage of advancing technologies is that one usually subscribes to later ones on offer. This can be a positive or a negative; by bypassing intermediate stages in the development of technologies, one could be said to have *leapfrogged* into newer and better ones. Typically, in hardware technology, one goes from vacuum tubes (first generation) to VSLI (fourth generation), bypassing in-between stages, without investing in outdated technologies, with significant savings, and no loss in outcomes. The following are indigenous cases of leapfrogging that have been an advantage for the common person.

2.2 Telecommunications

Until the 1990s, India was decades behind in telecommunications and its application to everyday life; for years, there was one government-run telephone company that turned out slow, inefficient, and bureaucratic; neither was it was inclined to consider the needs of the common person. With the opening up of the telecommunications sector, especially the mobile-phone platform, the common person was empowered, not just with a handheld phone, but one that could be used on-the-go, including text, messaging and images. One advantage the technology was that it did not require the laying of cables to each location, but instead used the airwaves. By the setting up of a tower, communication could be effected within a few kilometres radius. The introduction of communications technologies has had a significant effect in empowering common people in their daily lives; the effect has been in not only communication, but also economical and social change. With the introduction of mobile telephony in the year 1995, India became connected cutting through administrative procedures that had tended to curb private investment. In 2016, India's mobile penetration stood at a significant 1 billion connections, while its Internet user rate is 330 million, expected to reach 730 million by 2020 [2].

2.3 Transportation and Energy

The opening up of the automobile transportation sector, for 2-, 3- and 4-wheelers engendered competition within the private sector that has made a significant difference in the daily life of the common person. Today the move is from the internal combustion (I/C) engine to the electrical engine in transportation (Tesla cars, solar-powered flight). The standard automobile in the US gave 6 km/l (1975) now replaced by one that gives 13.6 km/l (2010); the standards will be increased to give 23 km/l by 2025. In the energy sector, the generation of hydroelectric power at one time required the building of extensive dams. The current possibility to harness energy from the sun or the wind has brought about a revolution in energy generation, accessible in remote regions without physically laying cables. Newer versions of appliances have become more energy-efficient; for example, a 60-watt incandescent lamp is today be replaced by a 6/8-watt LED lamp which gives the same amount of lumens, cutting the energy used (a savings of 85–90%), without giving off heat.

2.4 Governance

The computer in administration has brought about significant change in how bureaucracy functions. Decision-making was arduous, subject to frequent review and backtracking as part of the process. One of the early successes of computerisation was in the Indian Railways in the reservation of tickets. This brought about significant change. Another success was *e-governance*. The government of Andhra Pradesh (now Telangana) early on saw the potential of computerisation, and was instrumental in installing systems for administration. Other states followed, notably Karnataka, Tamil Nadu, as well as at the centre in New Delhi. Kerala went further, and moved its governance to the non-proprietary Linux® platform, much of it based on the free software system (FOSS). Also today, the coverage by the biometric Aadhaar identity card stands at over a billion records, covering 93% of the country's population, to be completed by 2017 [2].

The rapid growth of Bengaluru, the 'silicon valley' of India, the expertise of the private sector came together with the city administrators for the years 1999–2004 to help propel the city into a 21st century prototype for the rest of the country. This was the tentative Bangalore Agenda Task Force (BATF), on a public-private partnership model, meant to pave the way for 21st century administration [3]. Subsequently, the city administration took over from the adopted procedures of the combine.

Outside India, in the developed countries, where the process of '*smart governance*' was part of the process of development, the administration early on brought in computerisation for managerial purposes. In the USA, the General Services Administration (GSA, 1949-date) is responsible for the processes of documenting and installing systems that help in decision-making. In urban administrative and management systems, a major success was in Curitiba in Brazil, under the mayorship of Jamie Lerner; an architect and planner, he foresaw many of the problems of urban administrations, and came up with innovative solutions to ease urban problems, physical and infrastructural [4, 5]. He was able to bring first-world levels of urban governance to the third-world city of Curitiba. A contemporary example from the developing world is progress in the city of Bogota, the decision-making led by its mayor, Enrique Peñalosa [6], where the human aspects was taken seriously, with priority given to urban parks and public spaces; like Curitiba, transportation was organised along spines and fast lanes. Today, one of the better examples of smart governance is the systems in place for the 2014 FIFA Rio de Janeiro World Cup, which followed into the 2016 Rio Olympics. The challenge was taken up by the city together with IBM™. Today, with the advent of *big-data* and analytics, major decision-making can be accomplished in understanding/analysing urban problems.

3 Smart-Cities, Urbanisation and Development

The current global rate of urbanisation is around 52%; in India the rate is estimated at 31.3% (2015) [1]. Agriculture is the mainstay of the rural areas; the enhancement of conditions with modern technologies would ease the work environment, and better output. Overall, 94.1% (2015) of the population has access to a water source, but only 39.6% to sanitation facilities. Further, energy use per capita is 606 kg of oil equivalent (2013); and per capita electrical power consumption is 765 kWh [1]. The current emphasis on manufacturing (as adopted by China), needs to be rethought against the move from agriculture to manufacturing to the information age and needs to be co-ordinated to prevent efficiency losses, provide faster learning-curves, as well as to create synergies of innovation. The future of cheap labour might not sustain if the costs are distributed over the urban-rural divide.

The *smart-city* really belongs to the design of those, which are digitally connected, including its services and delivery systems. One of the advantages of '*smartness*' is that many of the services that one takes for granted could be given more efficiently, in terms of time, energy and accuracy. Gadgets for easing human labour for daily necessities, leisure or entertainment have become part of a world that is energy-absorbing, connected to the network, and amenable to control.

3.1 Smart-Cities in India

The program for *smart-cities* in India was announced more as an election promise—meant to perk the imagination of the people. From the early pledge of a 100 *smart-cities*, ground-realities had to be dealt with; from the initial ambitious arrangements, the specifications have been diluted to the extent that the conditions describe basic requirements for any well-designed city; the country really has few planned or well-functioning cities. A key issue is of infrastructure [7]. Future planned urban development also needs to include green and sustainable practices. Subsequent to the early declaration of *smart-cities*, the administration subsequently announced the development of 5000 *smart-village*s.

A clearer picture emerges knowing that multinational companies (MNCs) recognised the country as an emerging market, and hence are willing to invest and help develop, in exchange for a share of the pie. Published reports from management firms state that the country is headed for an urbanisation rate of about 52% by the year 2050 from [8]; these need to be looked at somewhat skeptically, since they are projections into the future. Without doubt, results can be achieved if it is taken as a priority; however, the underlying question is whether it is required at all. The reports predicted that the rate of urbanisation would result in a shortfall in many kinds of infrastructure and its associated services [8], which is acceptable enough if the assumptions prove correct; doubtless, one can take these as worst-case scenarios.

A two-pronged answer to this 'need for the urbanisation' issue can be mitigated by discouraging rural-urban migration, and by bettering the living conditions in both the rural and urban sectors. Czaika [9] suggests that much of the migration is for (rural/urban) populations are intrastate (73.4%/69.9%) as compared to interstate (23.3%/22.8%) or international (3.1%/7.1%). The overall interstate rate of migration is higher for males (43.8%); in comparison, most of the intrastate migration (87.3%) was female. An obstacle to the development of both cities as well as villages is the cost of real-estate; the assumption that these costs might not escalate during the related periods, and not factoring it into the equation would be economically detrimental. A hint to the high cost of real-estate can be understood when one observes large numbers of unsold/unrented apartments/offices—meaning they are investment vehicles, overbuilt and awaiting sale. In contrast, providing infrastructure to the rural areas including roads, transportation, power, telecommunications, etc. will help to discourage the migration, distribute inflationary real-estate values, making life in rural areas equally attractive, and help reduce congestion and pollution.

Today, it would seem that major factors that retard growth are land acquisition and infrastructure, which are almost codependent. Contrary to accepted notion, there are deeper issues of government apathy, private greed, downplaying fundamental-rights of existing landowners—often farmers and rural/tribal folk. The clumsy approach to finding solutions has to be rechecked from a judicial and fundamental-rights point of view, as well as of making them legitimate stakeholders in the process, with rights to land and compensation [10, 11].

4 Development, *Smart-Villages* and Panchayati Raj

"We have to make a choice between India of the villages that are as ancient as herself and India of the cities which are a creation of foreign domination. Today the cities dominate and drain the villages so that they are crumbling to ruin."

—*Mahatma Gandhi*, H., 20-1-'40, p. 423 [12]

4.1 Models of Development

Since the early advances of computer technology, efforts have been on to apply high technology to developing communities. Work by international academic and aid agencies have been documented from the mid-70s, in India and in other developing countries [13, 14]. Attempts by indigenous agencies in this direction are noteworthy – details of proposals indicate that issues anticipated then are similar to those currently on—meaning, yet to be resolved satisfactorily [15]. A proposal by the late President, Dr. A.P.J. Abdul Kalam (1931–2015), along with late Professor P.V. Indireshan (1928–2013) around 2004 was the 'Providing Urban Amenities in Rural Areas' named the *PURA* model of making the villages '*smarter*' to uplift the non-agricultural productivity through technology [16]. The enforcement of national planning standards would ensure the rise of living conditions; part of this is to ensure that basic infrastructure be given importance. Kalam proposed taking technology to the villages so that the multifold objectives could benefit rural people. *PURA* talks of three basic connectives—*physical connectivity* like roads and railways; *electronic connectivity* like telecommunications and the Internet; *knowledge connectivity* which would then result in *economic connectivity*; this would empower the villagers with employment opportunities and bring down poverty levels. The localised wisdom of the rural areas could be formalised that would be both indigenous to the location and conditions, and may find universal relevance. In 2001, 72.2% of the population lived in about 638,000 villages; the rest 27.8% lived in around 5100 towns and 380 urban agglomerations. An intent of developing *smart-village*s was to stem the exodus from the rural areas—by providing the facilities of the cities, the divide could be bridged, and the need for a move minimised. The uplift of the majority is a primary requirement in the country, in all spheres of life [17].

Subsequent to the announcement of *smart-cities*, the government made an announcement to develop 5000 villages with help from Microsoft™, Google™ and other MNCs in ICT. The GoI announced schemes such as e-Panchayat Mission Mode Project (ePMMP) [18]. A crucial inspiration is that with appropriate conditions, rural communities can also develop the ability to provide modern services [16]. As an exhibit for Microsoft™'s initiative to develop *smart-villages* in 2015, the government of Maharashtra picked the remote Harisal village in Melghat to study the possibilities. A backward village, Harisal is now a laboratory for integrating ICT into its daily life; the state further proposed to make fifty similar *smart-villages*, which it has now enhanced to a hundred [19]. As of date, backward Harisal has become the focus of much attention; a Wi-Fi now links its classrooms, it is connected for healthcare and telemedicine to some good urban institutions, electricity is partly supplied by solar panels, all residents have Aadhaar cards, bank accounts and ATM-cards; further it now serves as the hub for fifty other villages in the vicinity. Several other villages have now also been networked, some having international links to aid in agricultural exchanges, some for sales of their produce [19]. At the national level, the country's rural Internet usage is expected to rise significantly from 60 million in 2014 to 280 million by 2018 [2].

4.2 Concerns: Regulatory Frameworks, Language

Questions regarding the operation of *smart-cities* is of the regulatory system under which it will function. With the introduction of the 73rd and 74th Amendment (1992–93) to the constitution (also called the Panchayati Raj Act), the devolution of powers for development and governance has been handed to the urban local bodies (ULBs) as well as to the district *panchayats* down to *gram panchayats*. Since the implementation of this act is still in process in many states, there are questions of how *smart-cities* fits in [18]. The announcement of *smart-cities* by the central government now conflicts with its regulatory powers. To override its legislation, *smart-cities* were then sought to be classified as special economic zones (SEZs), and later by the use of a special purpose vehicle (SPV) [10].

Another issue facing the adoption of ICT technologies is of language. India is a country with 22 major languages in 13 scripts and 720 dialects; with so many, it is difficult for a person to interact with a system that primarily uses few languages for knowledge processing. The government has prioritised usage of local languages for these computational media. In this direction, the country is developing icon- and symbol-based interfaces for local usage. There are currently limitations in the absence of universal codes and translation schemes. Every state has its official documents, legal and executive systems encoded in the home languages. With a national literacy rate of 69% (2012), this is still a little away from being accessible to all citizens.

5 *Open-Source* Architecture, Settlements and Systems

5.1 Open-Source

A significant aspect in ICT to be considered is the incorporation of *open-source* (OS) elements and software. The scheme of *open-source* started in computer programming in the 1980s, when much of the software was turning proprietary—in terms of patents, copyrights, intellectual property (IP), royalties, etc. The development of free, *open-source* software (FOSS), copyleft, gave the developer the freedom to improvise, or to work at a collaborative level with interaction was an alternative way. This was initiated by organisations like the Free Software Foundation (FSF), which advocated developing and distributing software together with its source-code; there was freedom to improvise on existing *open-source* software, interacting with members of the community. Some current systems developed as *open-source* are software/operating systems like Linux®, Firefox™, Android™, etc.

A similar model of work—collaborative, networked, remote, with a touch of philanthropy in terms of time, effort and the ability to achieve significant results through joint effort has been taken up by wider groups, including architects and builders [20–22]. Some of this has been in disaster management—emergency shelters or low-cost housing for relief agencies, particularly during earthquakes, tsunamis or floods when expertise is needed in a hurry. These architects have advocated to freely make accessible ideas and knowledge that exists in the community. In sharing, the best of ideas could be brought out—discussions with like-minded individuals freely share thoughts and experiences in improving particular designs or concepts. Architecturally, this harks back to the initiatives of community building or models of vernacular architecture, one of the earliest processes in construction, and where there are no ideas of exclusivity, proprietary knowledge or similar; knowledge and information was shared without bounds. The idea is that architecture could be made *open-source*, especially in this age of significant networking, with collaborative efforts, crowd-sourced or even crowd-funded. Sinclair [20] cites examples from experience. Beyond this, many architects and designers have put their designs up for free download and use, even though they retain the design copyright, but waive the royalty or fees.

5.2 Open-Source *Vernacular Architecture and Traditional Knowledge Systems*

The concern that local or traditional knowledge is often lost, when one migrates needs to be reviewed. People who have lived on the land for generations possess an information-base that encompasses time-honored ideas of weather systems, flora and fauna, agricultural methods, land, soil-types, water and processes in Nature.

Similar comprehension would also extend to include traditional medicine and healing, building methods, local languages and dialects, folk arts, music, religion, mythology and folk tales—all of which inherently makes the world richer, pluralistic and colourful [15]. A system that is able to capture such knowledge, and be able to combine such data with modern scientific information needs documentation and exploration. Persons from the hinterland, forced to leave for the urban areas, are struggling for survival. On the other hand, s/he is the possessor of a significant knowledge. Localised information is useful; when such knowledge is crowd-sourced, it helps build up a larger body of facts which can be added to with each pass. It is inherently necessary that such information be collated. Today, information is open-ended, collaborative, and inclusive.

The idea is that such information is an answer in governance, but for efforts in the private as well as in the service/NGO sector. Such information is the basis for emergent subaltern histories, in developing geographical and geological databases, understanding folk mythologies, dialect variations, and a rich depository of traditional knowledge; this seems to be in tune with global thinking. Collaborative efforts help in a wider understanding of human and social affairs. In these days of shrinking geographies and communications, part of the efforts would be, as often put—to think globally and act locally.

6 Discussion

It can be understood that *smart-cities* are not a given, though there are some like Songdo in South Korea, or Masdar city in the UAE. *Smart-cities* in developed countries got built incrementally over time in tune with development. The general definition of a *smart-city* is of a connected, networked city that uses ICT for most functions—there would hardly be a part of everyday life, which is not touched by it.

In contrast, much of the basic infrastructure in the country continues from colonial periods, increasingly strained from growth—which needs enhancement, maintenance or replacement; the projections from increased urbanisation can be mitigated. On the other hand, policies for the development of *smart-cities*, like gated communities, indicate that they are to cater to already privileged sections of society, possibly at the cost of the rural population; for one, developing a hundred *smart-cities* are possibly cheaper than developing six lakh villages. However, this serves to amplify the rural-urban divide; this seems contrary to basic democratic principles, as well as serves as self-fulfilling prophesies of urbanisation being inevitable. Hence, it is important to look to enabling and empowering alternatives such as of *smart-villages* to stymie the so-called flood.

Alternates, theoretical or otherwise, to the *smart-city* are emerging, such as *open-source* peer-to-peer (P2P)-Urbanism [23]—where common people and residents are also stakeholders and participants in the development of the city, having or needing a say in the manner in which the city develops and functions. It indicates how qualitative city information is not the exclusive domain of city administrators or planners, but also belong to the city-users themselves. Together with this, the perception that to a large degree, the ones to judge the veracity of the schemes proposed, are the people who have to live in them; and that the users also might have ideas and opinions. People at the grassroots need to be empowered so that they can give opinions for themselves and their community, knowing what is best for them. A part of the idea is that government is a continuous process, not something that comes once every few years.

Open-source participatory traditional and vernacular information systems would allow people from remote areas to share and exchange traditional knowledge among the community. This is a bottom-up view of the world where structuring the hierarchy is centered on the individual or the community; this is inherently different from the usual top-down hierarchical view, and decision-making normally seen in events/activities that mostly involve the state. Such a process also becomes a means for documenting and/or capturing traditional knowledge for now as well as for the future.

7 Conclusion

Smart-cities, as they are currently defined by the administration, point to privileged areas having efficient infrastructure, which technically is expected from any city government. If however, by the use of ICT, everyday life in the city is enhanced, one is talking about valid *smart-cities,* where development and daily life is channelised and made easier, possibly hassle-free, through *e*-governance and '*smartness*'.

The assumption that urbanisation is a necessary part of the process of the future world needs to be examined in more detail. While mechanisation can remove some of the drudgery of labouring in the fields, one cannot do away with agriculture itself; agriculture is part of the process of living, and a lesser prominence might be given in terms of manpower and effort, as against currently; food security is still essential.

In India, with the development of *smart-villages*, life in rural areas could be enhanced, especially by providing/injecting knowledge and possibly channeling resources for better and making appropriate decisions. The inclusion of solar- or wind-driven power will empower residents in activities and daily routines, including education, communication, health or telemedicine. Basic infrastructure for potable water, proper sanitation, telecommunications, etc. should be extended to all parts of the country.

With the development of *open-source* systems, people in remote communities would be able to get broader or deeper information to make better decisions, tapping into worldwide information systems, and yet try to localise their solutions, to available resources. Exchange of knowledge, as well as knowledge capture and documentation would bring better livability to rural areas, secure in the knowledge that their world is as significant and meaningful.

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Design Intervention for Livelihood and Hygiene for Street Vending of Panipuri

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Abstract Collaborative approach between design and management education for design thinking to evolve socially responsible design is the prime focus of this study. A case study of design intervention in street vending of Panipuri for improvement of livelihood and hygiene has been considered. A team was developed comprising of students of management and design. Marketing research was conducted with the help of students of management. The major scopes of design interventions identified are (i) cart design to reduce load, increase mobility, ensure hygiene and attractive display; (ii) design to serve Panipuri to ensure hygiene, environment friendly disposal and customer delight. The marketing research findings were shared with the students of design using an online design ideation tool for idea generation [1]. Marketing-Research-Finding Sensitive Visualisation method was used for idea generation [2, 3]. The ideas were analyzed, screened and synthesized. Prototypes were developed for the new Panipuri cart and Panipuri serving.

Keywords Collaborative design · Design thinking · Design management · Design for livelihood · Street food vending

1 Introduction

Street food significantly represents the rich tapestry of India's multicultural fabric. The popularity of street food is mainly because of the unique taste, display and experience associated with it. A large section of urban poor depends on street food for their livelihood. Various complex issues are linked with the street food vending

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system viz. legal, administrative, hygiene, space, vulnerability of the vendors, livelihood, Indian food habit, daily life of the urban poor, Indian traditional food, culture, values, competition from other food providers etc. Therefore, a strategic design management approach was needed, for design intervention, to improve the livelihood of urban poor. Panipuri or Poochka or Golgoppa is a very popular street food in India. Health and hygiene issues are the major issues of concern in this context. The design challenge is to improve the livelihood of the Panipuri vendors, ensuring health and hygiene of the system. It has been observed that, due to unhygienic system of operation of the Panipuri vendors, many people suffered from water and food borne diseases like, typhoid, jaundice, diarrhea etc. Only enforcement of government rules cannot solve this problem. Design intervention with the help of strategic design thinking has a lot of potential to find a solution to this problem. Considering the complexities of design intervention in Panipuri vending, a collaborative approach of design thinking has been adopted for the study. Collaboration was done between students of management for marketing research and students of design for design solution. The exercise resulted in two major design interventions viz. (i) a new cart design for Panipuri vending (ii) edible serving bowl design for Panipuri. The designs evolved through this process have more potential to meet the design objectives.

2 Issues of Street Food Vending in India

Two sections of the society join the street food sector; one from the informal sector who has less educational qualifications and the other is from the formal sector that because of the downsizing of the economy and the merger of the economy has opted to choose for this sector [4]. Street food vendor's lack knowledge in safe food handling, environment, sanitation and hygiene, mode of food display, food service and hand washing, sources of raw materials, and use of potable water etc. Vending structures are also improper. Vending carts are not scientifically designed. Research revealed that adequate facilities for food washing, utensil cleaning were also not available [5]. Food safety intervention is one of the major issues to be considered in formulation of design strategy for street food vending. Food safety education is also a very crucial issue. It has also been observed that the young boys and girls were more conscious about the hygiene factor [6]. Consumer knowledge and attitude also influences the behaviour towards safety. Research revealed that lack of training about food safety and hygiene among vendors resulted in food contamination [7]. Usage of unhygienic water, preservation without refrigeration and environment with flies also act as a source of food contamination. Research also revealed that semi-processed food and unprocessed food showed contamination with *E-coli* virus, whereas processed food showed a relatively less contamination with *E-coli* virus [8]. Research suggested that street food vendors should practice safe hygiene as an integral part of their business; but due to their low income level they often compromise with the quality of food and hygiene. An Indian initiative of Food

Safety and Standards Authority and the National Association of Street Vendors has been playing a vital role in this context [9]. Research has also suggested that by installing the water supply kiosk for vendors, and up-gradation of pavements suitable for street food vending, can significantly improve the hygiene condition. There is a need to study the entire issue from a sustainability point of view [10]. Research has demonstrated that, a simple inexpensive system for hand washing and beverage storage can reduce bacterial contamination of street-vended beverages. Reduced contamination, in turn, likely reduces the probability of transmission of cholera and other bacterial illnesses [11]. Along with hygiene, branding of street food is also very crucial and design intervention in branding of street food is the need of the hour [12].

In the city of Guwahati, Assam, India there is a growing market of street food vending. The city has a lot of potential for tourism and therefore street food vending may play a very crucial role. It has been recorded that there are 7182 street vendors in Guwahati city and with the enactment of the law day by day population has been increasing at a rapid rate. It has been observed that the vendor fails to provide hygienic food. Customers from middle and higher income groups are also fond of street foods of Guwahati, but they are skeptical about the hygiene factor. The major street foods in the city are Panipuri, Sugarcane juice, Momo, Rolls, Chana-chur, Luchi-ghugni, Goja, Jilapi, Singara, Chat, Bhokapitha, Tea etc. Among all the aforesaid street foods, Panipuri is one of the most popular street food. In this study, a case of Panipuri vending has been considered.

3 Methodology

A team was developed compromising of three students of management and two students of design. Marketing research was conducted with the help of the students of management discipline. The prime focus of the marketing research was on study of user behavior and various issues of Panipuri vending. The study was conducted using visual ethnographic narratives, observations and interviews. The study suggested two major scopes of design interventions. The first one was the cart design to reduce load, increase mobility, ensure hygiene and attractive display. The second one was to develop innovative design to serve Panipuri to ensure hygiene, environment friendly disposal and customer delight. The findings of the study were shared with the design students with an online design ideation tool [1]. In the online design ideation tool, Marketing-Research Finding Sensitive Visualisation (MRFSV) method has been used [2, 3]. Further user research was conducted by the design students to get a better insight into the problem. Several ideas were generated for Panipuri cart design and Panipuri serving design. Ideas were developed to address the specific design problems identified in the MRFSV tool. Ideation sketches were discussed, analysed and synthesized. Wireframe models were developed for Panipuri cart design. The wireframe models were simulated and tested with the help of a mannequin. With the help of this exercise, final concept of the Panipuri cart was evolved. Product detailing was done in 3D Modeling. 1:1 scale prototype was developed for the simulation and validation. For Panipuri serving design, the prime focus was on development of edible design for Panipuri serving. Various materials and forms of edible packaging and serving were explored. Prototypes were developed and tested for usability and feasibility. After the finalisation of the design, prototype was developed. Usability testing was done with focus group discussion.

3.1 Marketing-Research-Finding Sensitive Visualisation (MRFSV) Online

The online design ideation tool aims to integrate professionals and students of management with professionals and students of industrial design [1]. With the help of the online application, the author has generated on-line MRFSV questionnaire on the basis of the field studies conducted by the students of management. The online MRFSV questionnaire was sent the design students for their responses. The software tool has automatically analysed data using the logic of MRFSV method [2, 3]. The design brief was created on-line on the basis of the analyses of MRFSV questionnaire. The comprehensive design brief was sent to the design students for design ideation. On the basis of the design brief, design students generated several design concepts focusing on the issues and elements responsible for achieving the design objective. Design students uploaded their design ideas in the form of text and images in the web based application. The design ideas were further improved on the basis of the discussions and feedbacks.

3.1.1 Genesis of Marketing-Research-Finding Sensitive Visualisation (MRFSV)

The idea of MRFSV was originated from the abstract thinking of Context Sensitive Visualisation (CSV) method [13]. In the MRFSV method, the designers are required to, understand user requirements and its association with the design problem [2, 3]. Designers are required to define user requirements and specific design problems in a structured way. In the context of the specific user requirements, designers are required to visualize design solutions for the specific design problems related to user requirements. Then designers develop the final model after synthesizing all the visualizations of design solutions.

4 Results and Discussions

The marketing research study revealed that there were four types of Panipuri vending carts available in Guwahati viz. (i) stand cart (ii) two wheeler wooden cart (iii) four wheeler wooden cart and (iv) four wheeler metal cart. It has been observed that the most preferred vending cart design used by the Panipuri street vendors was the ‘stand cart’. The street vendors faced several problems in the present Panipuri vending cart. The major design consideration was to make it convenient for the vendors to carry it. The other major requirements were to ensure the attractive display of the Panipuri. In this aspect they opined that their prevailing display method was very effective to draw customer attention. The study identified following problems of existing Panipuri serving. The problems were (i) improper disposal system (ii) pollution and environment hazards (iii) non attractive serving bowl (iv) mismatch with the food type and experience (v) limited scope of improvement or modification in the existing design, material (vi) vendors were not accepting any other material except paper due to cost (vii) health and hygiene issues in serving and packaging made of newspaper and plastic.

4.1 Design for Panipuri Serving

On the basis of the marketing research findings, initial ideations and discussions the following design objectives were set; viz. to select non-hazardous, environment-friendly and economic material for Panipuri serving and to design an innovative, implementable and adaptable design for serving. All the available alternatives of materials for Panipuri serving were observed and discussed. Following is the summery comparisons of materials (Table 1).

4.1.1 Prototyping of Panipuri Serving

Initially paper models were made for conceptualisation. The paper models were further modified. The paper models were then replaced by edible serving bowl. The edible bowl concept was also developed in three stages. Modifications for improvement were done at each stage. Following is the description of the final concept and related process.

The dough was prepared using common Indian household ingredients. The ingredients for two Panipuri serving bowl are:60 gm Atta flour, 20 gm semolina, one pinch asafetida, one pinch carom (ajwain), salt to taste and 13 gm oil, water as required to make hard dough. The dough was rolled and then given a bowl shape. Altogether two trails were made with baking and deep frying (Figs. 1, 2, 3 and 4).

Table 1 Comparison of materials for Panipuri serving

	Material	Good for health	Generate waste?	Biodegradable?	Recycle?	Cost	Have to make/buy
	Paper with Aluminum foil	Yes	Yes	Partly Yes	No	Compare to Magazine paper high	Buy
	Polystyrene foam (Thermocol)	No	Yes	No	No	Compare to Magazine paper high	Buy
	Leaf	Yes	Yes	Yes	No	Compare to Magazine paper high	Buy
	PVC	No	Yes	No	No	Compare to Magazine paper high	Buy
	Clay	Yes	Yes	No	No	Compare to Magazine paper high	Buy
	Magazine paper	No	Yes	Yes	No	The cheapest	Make
	Wafer	Yes	No	NA	NA	Compare to Magazine paper high	Buy

Fig. 1 Ingredients for the edible bowl

Fig. 2 Preparation of the dough

Comparisons were made between serving bowl developed through fried and baked process with respect to wafer bowl. The criterion for comparison was whether it retained the shape while in contact with water, overall experience, production and future scope (Table 2) (Figs. 5 and 6).

Fig. 3 Rolled dough

Fig. 4 Bowl shaped dough

The fried serving bowl was found better than the baked and the wafer bowl. Detail comparison is described in Table 2. The concept evolved also ensures hygiene. It eliminates germs and contaminations during production, serving and disposal.

Table 2 Comparison of serving bowl developed through fried and baked process with respect to wafer bowl

Package	Retain shape in contact to water?	Overall experience	Production	Future scope
 Fried bowl	Yes	It retains water for longer time, which is important in context to Panipuri. It is crispy and easily breakable. Smell of the Ajwain and Asafoetida is blending with the whole and enhancing the total experience. Hygiene is ensured	Mass production is possible, if proper die is designed. Also kills germs during frying	It is crisp in nature and in future other street foods like 'chaat' can be served
 Baked bowl	Yes	It retains water for longer time, which is important in context to Panipuri. But, baking makes the package harder and affecting the total experience. Hygiene is ensured	Mass production is possible, if proper die is designed. But for that bigger size oven will be required. Also kills germs during baking	Though it is hard, but it can be used with many other food
 Wafer bowl	No	It does not retain water for longer time. In contact with water it becomes soft quickly and it is effecting the whole experience. Hygiene is ensured	Mass production is possible, but it takes more time to make one piece	It is good for serving ice cream and renowned brands are doing that. Food having less water content may be server better

Fig. 5 Fried bowl

Fig. 6 Baked bowl

4.2 Cart Design for Panipuri Vendors

On the basis of the marketing research findings, initial ideations and discussions, the following design objectives were set; viz. to redesign a cost effective cart for panipuri to reduce health issues of Panipuri vendors and to eliminate hygiene issues; ensuring attractive display. Using the collected information, brainstorming session was conducted. 6 designers and 1 ergonomist were involved in the brainstorming session. Basic product and system needs were sorted. Required functions of the cart to solve the existing issue were analyzed and noted. After brainstorming design constraints were set and these were: (i) Load should be distributed in case of stand cart to ease the carrying process, (ii) Vendor should lift and put down the cart easily.

Different combinations of load carrying options were explored and discussed. Wireframe models were developed and simulated with the mannequin. Exploration resulted into foldable and wearable stand cart, which would minimize the effort of lifting and putting down on the ground. But, analysis revealed that, the foldable cart loses its robustness. Therefore, only wearable option was considered for further ideation, model making and simulation. Initial sketches were generated followed by development of wireframe models. Models were refined based on the finding of simulation (Figs. 7 and 8).

Fig. 7 Wireframe models and simulations

Fig. 8 3D Modeling and simulation

4.2.1 Virtual Model and Mock-up Model of Cart for Panipuri Vendors

Final concept was selected, developed in 3D CAD and usability component were analyzed virtually for different postures. After that a 1:1 model with PVC pipes was developed and tested with focus groups (Figs. 9 and 10).

User testing successfully validated the usability of the design. It has been found that the design would be able to reduce the carrying effort of the Panipuri vendors. User testing suggested the use of cane and bamboo for development of the design.

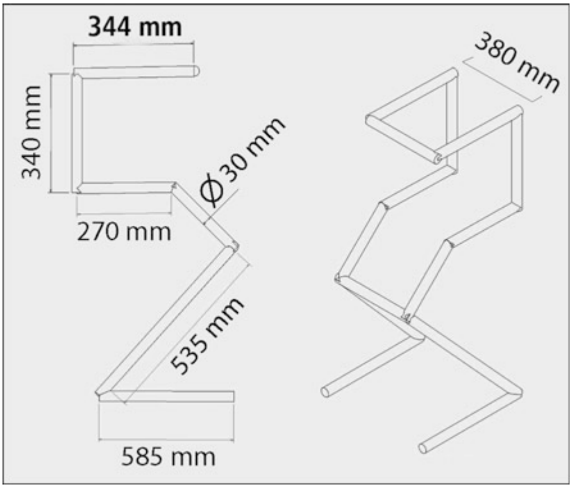

Fig. 9 Dimensional drawing of the cart

Fig. 10 1:1 Model made and user testing

5 Economic Justification

The new concept of serving bowl will create differentiation in the market place. Therefore, the Panipuri vendors will be able to attract more customers, compare to other vendors. The field study revealed that, it would create a new position for Panipuri and they will be able to charge premium price. The new cart design can be easily manufactured by local craftsman with locally available materials, viz. cane and bamboo. The new cart design will improve mobility of the vendors and will create a new experience for the customers. This will result into higher revenue generation; thereby improve their livelihood to a large extent.

6 Future Scope and Conclusion

The research suggested refinement of the design for Panipuri serving and cart designs with more field trials. Design of die for making Panipuri serving bowl has to be developed. The cart has to be made in cane and bamboo. Jigs and fixtures for ease of manufacturing of the cart have to be developed. The study strongly establishes the fact that, strategic design intervention in street food vending in India is one of the thrust area for design research. The research community engaged in design for development can make a significant impact in improvement of livelihood of street food vendors in India with innovative design strategies.

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Life Cycle Assessment (LCA) to Assess Energy Neutrality in Occupancy Sensors

Tarun Kumar and Monto Mani

Abstract Life Cycle Assessment (LCA) is a quantitative model which attempts to assess the aggregated environmental impacts of various life cycle stages of a product and helps in various sustainability support decisions for product design and development. This methodology has been standardized by ISO and been accepted by various organizations and designers. The present study focuses on Life Cycle Assessment (LCA) as a tool for Energy Neutrality Assessment with the help of a case study of occupancy sensors in net energy conservation assessed through life cycle energy study and simulation methods provided by LCA tools. Occupancy sensors aim to reduce energy consumption by switching off energy appliances when the monitored space has no occupants. Moreover, it is evident that though it saves some energy at the place of installation but these measures needs to be evaluated from Life-cycle energy framework to effectively understand the net energy conservation over the life cycle of such devices. This approach focuses on two dimensions of investigation, the former being the life-cycle energy involved in the adoption of such a device, while the later concentrates on the environmental aspects of various life cycle stages. In this case study, Occupancy Sensors have been studied for their adoption in typical office buildings. The study would compare the effectiveness of occupancy sensor in reducing net energy consumption computed over its life span with the aid of existing LCA Simulation tools and models. The results reported measures the effectiveness of such measures and devices in net energy conservation and its environmental impacts, accounting for the data uncertainty and limitations in data availability.

Keywords Occupancy sensors · Motion sensor · Life-cycle application energy

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1 Introduction

The percentage of building energy use in final energy use is highest (47%) in India, followed by china (34%) [1, 2]. Hence, Energy saving potential is also quite high in this sector owing to energy deficit in all five electrical grid regions of India varying from 3 to 18% [3, 4]. The global cost of lighting is as high as $230 billion per year [5]. Lighting energy comprises of 15–20% of total building energy consumed in commercial office buildings while 20–40% of total building energy in residential buildings in India [6]. Hence, it also contributes majorly in global greenhouse gases emission and consumption of fossil fuels and related pollution [7].

2 Working Principle and Design

Use of motion sensors (occupancy sensors) are one way to minimize the lighting load by switching On/Off the appliance whenever the building space is unoccupied [8, 9]. The Passive Infrared (PIR) based occupancy sensor senses the change in temperature pattern of the space due to occupancy of people. These PIR sensors don't emit energy for sensing occupant information and hence are called 'Passive' [10, 11]. The average energy savings estimates by such PIR based occupancy sensors in office buildings is 26% (core hours[1]) to 31.7% (average of all data) [12]. These energy savings are important because as less as 1% reduction in load due to demand response can lead to 10% reduction in wholesale electricity prices, while 5% reduction would cut the wholesale electricity prices by 50% [13].

3 Life Cycle Assessment and Energy Neutrality Concept

The word Sustainability originates from Latin word *sub-tenere*, later transformed into '*sustinere*' which means 'to hold up' [14]. According to most widely quoted '*Brundtland Commission*' report 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' [15]. One missing aspect in this concept, If applied on products, can be said to be the quantification of sustainability i.e. How sustainable, a product is with respect to other products. Hence, the challenge is to quantify sustainability for products, processes and services for sustained access to energy adopting energy conservation measures.

[1]Core hours are defined to be between 7.5–10 h per day when the office building is being used [12].

The concept of life cycle assessment (LCA) addresses the environmental aspects of a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave) [16]. LCA is primarily a quantitative model used to support sustainability decisions. Moreover, LCA can't tell if a product is 'sustainable' or 'environment friendly' in absolute terms, but it can only provide options which are relatively better in terms of various sustainability indicators [17].

The LCA has been standardized globally by the International Standards Organization (ISO). It developed four standards in the ISO 14000 series (ISO 14040–14043), which specifies minimum requirements to perform an LCA [16, 18–22]. These standards also define the framework for doing a LCA study as shown in Fig. 1 [22].

The reliability of LCA results depend upon the data collected from different countries, at different times and data collected for different purposes other than LCA and different methodologies [23–25]. Various approaches to improve the reliability has been used by LCA practitioners, which include sensitivity analysis and quantitative and qualitative uncertainty analysis [24]. The challenges faced by LCA studies are data availability, access to relevant data and data reliability. The value of LCA as a tool would increase significantly if the gaps in the validation methodology is addressed [26].

Energy neutrality, is a term adopted and defined in this study, to imply that any device adopted with an intent for conservation and/or generation of energy has already recovered (through installation and operation) the energy involved in its realization (and installation). The energy neutrality study would be done in addition to LCA analysis of an occupancy sensor to see the possible energy savings potentials with respect to its total Life-Cycle energy use and various associated environmental impacts.

4 Methodology of Investigation

4.1 Objective and Scope of Study

The objective of the LCA was to study and compare energy consumed by different stages of occupancy sensors over its entire life cycle and to analyze the effectiveness in energy saving by occupancy sensor in an office building scenario. The LCA includes the cradle to grave analysis of various life cycle stages of Occupancy Sensor: Motion sensor production from raw materials, Assembly of sensor system electronics, Occupancy sensor housing and packing, Product packaging, Transport phase, Use phase, and End-of-Life phase. The study uses GaBi 2015 Database, Eco-invent 3.1 database, Industry data sources and primary data sources collected

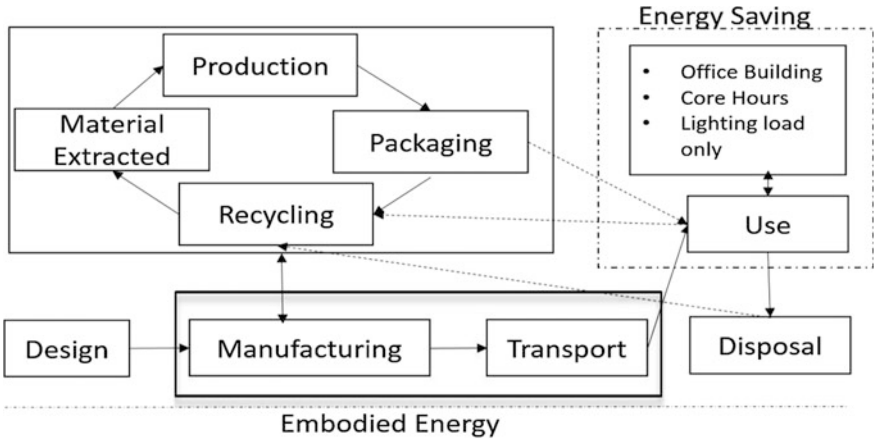


Fig. 1 Figure showing energy neutrality diagram for the occupancy sensors

by authors. Appropriate assumptions[2] are made wherever data can't be found based on a sensitivity analysis on *GaBi 6 software.*[3] Also, the CML 2001 method was used for calculation of impacts. While, the scope of this analysis covers many of the primary processes and flow, some secondary processes (i.e. transportation of raw materials for packaging) could not be included. The country specific data from China and India were taken wherever available. Many India specific data is lacking in these databases, hence the results of the study are only notional and serve the purpose of illustrating the concept and its applicability.

4.2 Product Analyzed and Software Used in the Study

The study was done on a specific PIR (Passive Infrared) based occupancy sensor from GASIM (GST07) imported from Shanghai by a local company via sea route. The mentioned occupancy sensor was disassembled and its components were identified for detailed component-level LCA. The mapping of various input and output flows of material and energy was done for all production processes. Moreover, many of the Life-cycle processes, including transportation, were also mapped. The packaging of the product was traced and divided into primary, secondary and Tertiary packaging. A *LCA simulation* study was done for most of the flows, processes and parts by GaBi 6 Educational software. A separate LCA of

[2]Since we are using the same databases, we are assuming that the data is internally consistent with time and location. This assumption is only to facilitate a comparative appreciation of the Energy Neutrality concept as applied to various luminaires.

[3]GaBi 6 is a powerful LCA tool for product and process sustainability analyses.

product packaging and transportation was done by *COMPASS*[4] *software* Moreover, calculations for energy payback time for one occupancy sensor was done in an office scenario.

4.3 Functional Unit and System Boundary

The functional unit was taken as production of one unit of occupancy sensor installed in an office building scenario. The system boundary was taken as manufacturing and transport stages for Energy Neutrality assessment. Moreover, the system boundary for LCA study was from cradle to grave (manufacturing processes to end-of-life) scenario.

5 Experimental and Simulation Results

The following formula was deduced for calculation of Payback Time (T) in the study.

For the energy neutrality condition as defined in this study, Embodied energy of the occupancy sensor should be equal to the energy saved by the occupancy sensor when in use.

Embodied energy of the occupancy sensor = Energy saved by the occupancy sensor in its lifecycle (Table 1).

$$E_{M.S.}(t) = \int_0^t E_{B.E.}(t) \cdot dt \tag{1}$$

$$E_{M.S.}(t) = \sum_{I=1}^{n} Epi + \sum_{j=1}^{m} ERj + Eo \cdot (t) + Em \cdot (t) \tag{2}$$

$$E_{pi} = E_{mf} + E_T + E_A + E_{in} + E_{pk} \tag{3}$$

$$E_{B.E.}(t) = (E_{conv} - E_{occ}) \cdot (T) \tag{4}$$

Hence from (1), (2), (3) and (4), we get the following formula;

[4]COMPASS (Comparative Packaging Assessment) is an online software solution for packaging designers and engineers to assess the human and environmental impacts of up to four package designs side-by-side.

Table 1 Calculation of total life-cycle energy of one unit occupancy sensor

Occupancy sensor	Total energy consumed in the production processes	Total energy consumed in the recycling processes	Operational energy	Maintenance energy	Total life-cycle energy (Megajoules/Device)
Formulae/ symbols	$\sum_{i=1}^{n} E_{pi}$	$\sum_{j=1}^{m} E_{Rj}$	$E_o \cdot (t)$	$E_m \cdot (t)$	$E_{M.S.}(t)$
Components	$(E_{mf} + E_T + E_A + E_{in}) + E_{pk}$	$E_{R1} + E_{R2}$	$E_o \cdot 10$	$E_m \cdot 10$	
Energy calculated	391 + 114.4	56.1	38.9	5 (±2)	
	505.4 MJ/Device	56.1 MJ/Device	38.9 MJ/Device	5 (±2) MJ/Device	605.4 (±2) MJ/Device

$$T = \frac{\mathrm{Eo} \cdot (\mathrm{t}) + \mathrm{Em} \cdot (\mathrm{t}) + \sum_{i=1}^{n} \mathrm{E_{pi}} + \sum_{j=1}^{m} \mathrm{E_{Rj}}}{(\mathrm{E_{conv}} - \mathrm{E_{occ}})} \tag{5}$$

$E_{M.S.}(\mathrm{t})$ =	Embodied energy for life cycle time period T
$E_{B.E.}(\mathrm{t})$ =	Energy saved by occupancy sensor in the building over a time period t
$\mathrm{E_{pi}}$ =	Energy consumed in the *i*th production process
$\mathrm{E_{Rj}}$ =	Energy consumed in the *j*th recycling process
$\mathrm{E_o}$ =	Energy consumed in operation over life cycle
$\mathrm{E_m}$ =	Energy consumed in maintenance over life cycle
$\mathrm{E_{mf}}$ =	Energy consumed in Manufacturing
$\mathrm{E_T}$ =	Energy consumed in Transportation over life cycle
$\mathrm{E_A}$ =	Energy consumed in Assembly of one product
$\mathrm{E_{in}}$ =	Energy consumed in installation
$\mathrm{E_{pk}}$ =	Energy consumed in Packaging in all stages
$\mathrm{E_{conv.}}$ =	Energy consumed by luminaires in conventional setting (without sensor)
$\mathrm{E_{occ.}}$ =	Energy consumed in by luminaires with occupancy sensor

6 Data Interpretation

The occupancy sensor was connected to three types of luminaires[5] (a) LED light (3 W) (b) Incandescent light (60 W) (c) Fluorescent light (40 W); and the energy savings were recorded. The Energy Payback time given by the formula (5) were calculated for three types of luminaires as shown in Table 2. The ratio of weight of the occupancy sensor to the wattage of load connected to it (termed as sensor-*gram/load-wattage* (γ) in this study) seems to closely follow the graph of Payback Period (T). It can be said that gram/wattage ratio should be lower for lesser energy payback time (T).

Monte Carlo Analysis, which can perform stochastic modelling has been a promising technique to deal with data uncertainty in LCA studies [27, 28]. The uncertainty in the data points has been taken as $\pm 10\%$ as shown in the Fig. 2 based on *Monte Carlo analysis* through GaBi software.

From Fig. 2, we can infer that the gram/wattage ratios should in the range of 0–10 ($0 < \gamma \geq 10$)for occupancy sensor to be energy neutral. Also, the energy positive character of occupancy sensors depend on the value of (γ), which should be nearer to 0 in the range of $0 < \gamma \geq 10$. However, the interpretation of (γ) needs to be further investigated for its validity for correlation with payback period. It must

[5]The Embodied Energy of Luminaires has not been accounted in the energy neutrality study and would be taken up in studying the concept subsequently.

Table 2 Payback period and gram/wattage calculations for one unit occupancy sensor

Type of luminaire	Energy saved by one occupancy sensor for the following connected load type (MJ per device) $E_{B.E.}(t)$	Total life-cycle energy of one occupancy sensor (MJ per Device) $E_{M.S.}(t)$	Payback period T (in years)	Weight of device/load connected (γ) (sensor-g/load-watt)
LED light (3 W)	55 MJ/Device	605.4 MJ/Device	11.01	39.33
Fluorescent light (40 W)	231.6 MJ/Device	605.4 MJ/Device	2.61	2.95
Incandescent light (60 W)	1104.5 MJ/Device	605.4 MJ/Device	0.54	1.96

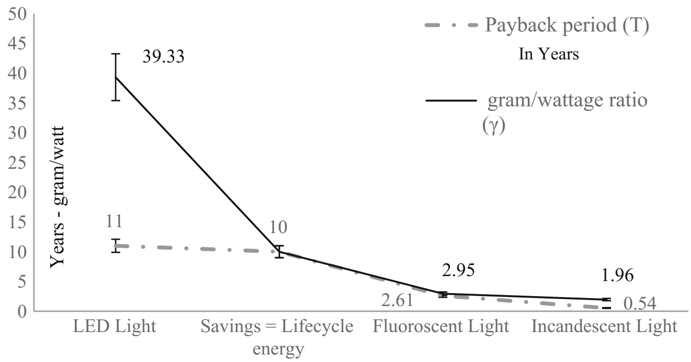


Fig. 2 Graph showing payback period and gram/wattage ratio of three different types of luminaires

be noted that the mean service lifetime of Incandescent lamp and fluorescent lamp is much shorter than that of occupancy sensors. Moreover, only the LED lighting fixtures have a comparable service lifetime. Also, from the analysis, it can be inferred that Fluorescent light in an office scenario has γ more than 2.5, while LED fixture has γ more than 10. Hence, the effectiveness of an occupancy sensor depends on the type of load connected (type of luminaires) and their life time too.

The other simulation results from GaBi software as depicted in Fig. 3 shows significant decrease (1.6 times approx.) in Total Life-Cycle energy ($E_{M.S.}(t)$) for an occupancy sensor which would be locally produced in India as compared to one produced in China. This decrease is due to the high energy incurred in oceanic transport phase.

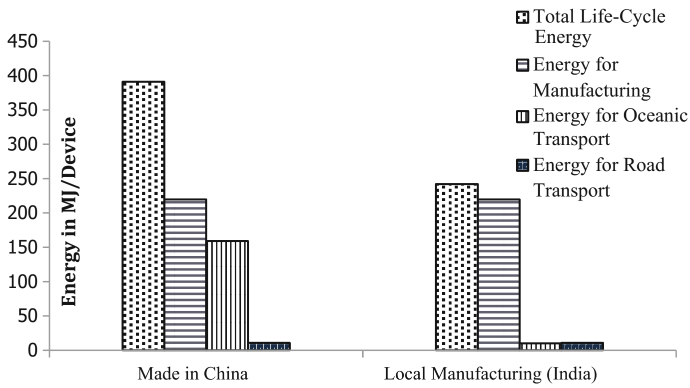
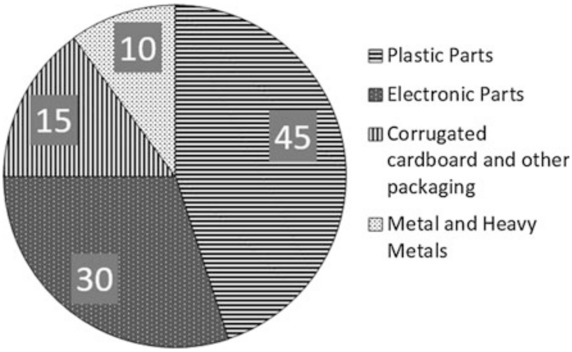


Fig. 3 Graph showing total life cycle energy and energy consumed in different life cycle phases in China and India as analyzed by GaBi 6 software

Fig. 4 Pie chart showing the percentage of each type of waste in total waste produced by occupancy sensors



Also, Fig. 4 shows that Plastic waste comprises the largest portion (45%) followed by Electronics parts (30%), while Packaging materials like corrugated cardboards, User manual etc. makes 15% of total waste. Moreover, it's the metals and heavy metals (10%) which causes significant Eco toxicity (analysis by GaBi 6).

Furthermore, the results of LCA analysis of Packaging materials by COMPASS software shows that the corrugated cardboard consumes most energy (29.2 MJ-equiv), emits most GHG Emission (1.07 kg CO2-Equiv) and also has large human impacts and Eutrophication Potential amongst all packaging materials. While, other plastic packing components contributes the largest in water consumption (2.24 l/Device), aquatic toxicity 0.041 CTUe/Device), Mineral consumption (0.02 kg/Device) and biotic resource consumption (0.05 m3/Device).

7 Conclusions

The study shows the ineffectiveness of occupancy sensor in reducing net energy consumption computed over its life span and that of the appliances. The adoption of occupancy sensors in an typical office building scenario is not very effective because the net Life-cycle energy consumed exceeds the energy saving accruing due to its adoption. Transportation contributes hugely to the cost, embodied energy and pollution caused by occupancy sensors. Packaging (including corrugated cardboard and plastic packaging) of occupancy sensors are also a major contributing factor in energy consumption and environmental impacts. Heavy Metals and Rare-earth metal are the major contributing factors in pollution caused and electricity used. Improper disposal causes toxicity in water and land. The results reported measures the effectiveness of occupancy sensors in net energy conservation and its environmental impacts, partly accounting for the data uncertainty. The limitations imposed by lack of data availability, data incorrectness and data uncertainty needs to be addressed properly through standardization of methodology and databases used in LCA studies.

8 Recommendations

Local manufacturing of these devices will reduce transportation cost and reduce the pollution and life-cycle energy significantly. Packaging is highly polluting and energy consuming stage of Life cycle of occupancy sensors. Eco-friendly Packaging can be done locally with least amount of plastic involved. Moreover, Recycled materials should be used as much as possible.

We should reduce the use of these sensors only to places which has lesser use time (i.e. corridors and restrooms) better reuse of components and recycling techniques are the need of the hour. Luminaires with lesser energy requirements (i.e. LED) eliminate the use of occupancy sensors for Lighting loads. The Embodied Energy of Luminaires has not been accounted in the energy neutrality study and would be taken up in studying the concept subsequently.

Various user scenarios needs to study in detail as it might significantly change the results and needs to be taken up in further studies.

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Micro Solar Energy Systems: Product Design Intervention Facilitating Sustainable Development for Rural North East India

Brajesh Dhiman, Mrinal Krishna Chaudhury, Sudip Kumar Deb and Debkumar Chakrabarti

Abstract Energy Access is one of the prime concerns particularly for the development of North Eastern India. Though this region is a hub of natural resources, yet it is deprived of easy access to commercial energy including, energy for domestic and other small scale applications. Complete Rural Electrification may not be possible in this part of the country through a conventional grid due to its remote geographical locations, dispersed population density and the high cost of extending transmission lines. This creates an imbalance leading to the lack of basic amenities and thereby economic backwardness for the north east region persists. In this regard, decentralized energy solutions become the part of development with respect to local self-reliance. In general, the aim of this paper is to demonstrate possible benefits of a product design intervention for Micro Solar Energy Systems and Micro Enterprise, upscaling rural livelihood.

Keywords Micro solar energy system · Product design · Sustainable development · Decentralized energy · Rural north east India

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1 Introduction

Power scenario is that in India alone about 237 million people don't have access to electricity [1]. There are 19,706 un-electrified villages, in which 4169 un-electrified villages alone are in the north-eastern part of India [2]. This comprises about 21% of total un-electrified villages of the country. The north-eastern region is among the most energy oppressed part of the country due to limitations of technical difficulties and financial tasking for grid extension that results in poor industrial base and high un-employment rate [3]. Emergency arising due to natural calamities also draws attention towards developing a portable and energy independent source as an appropriate solution. With moderate socio-economic status and low per capita electricity consumption of the region, solar micro-energy systems become promising alternative towards energy reliance of the people of rural north east India (Fig. 1).

Micro Solar Energy System comprises of products like Solar Home Systems (SHS), Pico PV (Photovoltaic) and Solar Lanterns (SL) and is the most economical entry point for solar power applications suitable for rural use. In addition to Illumination, Pico PV provides Mobile and Lantern charging options with benefits like low-cost and off-grid functionality. Such small-scale energy devices provide a good scope of opportunity for design customization, and can play a pivotal role in building energy reliance with high dissemination rate. There are other renewable energy systems like Solar Mini Grids, Wind, Micro-Hydro and Biomass, but installation cost of such system is much higher and they have resource specific limitations within the north eastern region of India.

Basic parts of a Solar Home System consist of photo voltaic module to charge a battery bank and provides DC output for running luminaries, DC Fan, mobile charging, LED TV etc. The charge controller is a vital part of the Solar Home

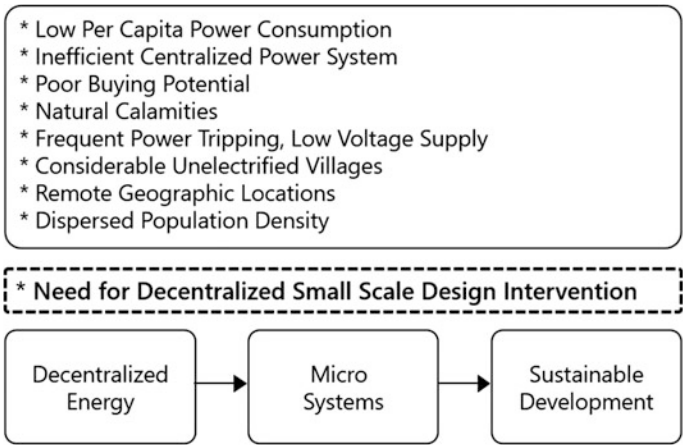


Fig. 1 Need for micro energy based design intervention (*Source* Author Compilation)

System which controls and regulates the energy to the battery bank. Pico PV is a small scale portable alternative to Solar Home System which fulfills basic energy need. A solar lantern is a small scale lighting device retained in a housing made of plastic or metal that encompasses a rechargeable battery and required electronics. For SL the battery is charged using PV module or the PV module is sometimes integrated into the solar lantern itself [4].

The most common solar photo voltaic applications executed in the south Asian region includes solar home systems (SHS), solar lanterns (SL) and solar PV mini-grids (SMG) [4]. Many studies have emphasized the impact of PV electrification to improve the socio-economic status of the rural area [5–7] clean energy supply, protecting indoor air quality and the contribution to greenhouse gasses alleviation from the use of a kerosene lantern or wick lamp for lighting.

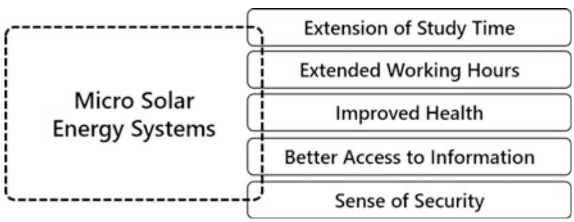
Studies have also revealed that how renewable energy technologies have contributed towards enhancing rural livelihood [7–9]. A study conducted in Bangladesh concluded that if Micro Solar Energy Systems are used according to specification, it can improve the socio-economic status of rural people (Fig. 2).

In poor developing countries micro-solar energy systems are used for outspreading light to areas that could not be touched with grid electricity. Given the scope of customization, Product Design intervention for such Micro Devices becomes very valuable, considering its importance for base of the pyramid, in this context the energy deprived rural community of the north-east.

The newness of the idea is in using the design based framework for participatory development of the rural region and other similar pockets of the country. This paper focuses on product design intervention to facilitate sustainable development that utilizes local resources and considers the customized requirement of rural user, leading to the democratization of design for rural productive use. Proposed Design Intervention may integrate renewable energy with other development initiatives like Local Skill Up-gradation, better Socio-Cultural acceptance, and the creation of new opportunities for livelihood generation.

The paper goes in coherence with current Govt. of India initiatives like Make in India, National Solar Mission of setting 100 GW of Solar Power by 2022 and National Skill Development Mission launched in 2015. Such Symbiotic Relationship between Product Design, Renewable Energy, and Society could possibly give New Orientation and Value Addition to 'narrowly focused' existing energy programs of government missing out on to the valuable 'down to up' approach for design. The participatory approach for decentralized energy

Fig. 2 Benefits of MES electric lighting (*Source* [10])



intervention holds good promise for rural development in context of the North-East Region of India [11].

2 Resources for Rural Development

Local consideration can help poverty reduction by creating an avenue for entrepreneurial opportunities. North-eastern part of India is quite rich in terms of local resources like bamboo, which is widely available across the rural domain of the region and across different parts of India. The country has second-largest bamboo resource in the world of which two-third lies in north eastern region. It has good employment potential and major workforces involved are the rural poor [12]. Development of novel applications of such locally abundant resource may fulfil economic, social and environmental objectives along with cultural and social growth [13, 14].

Bamboo as material is renewable, widely available, low-cost and eco-friendly. With the wide range of applications and high renewability, it occupies a significant position in twenty first century [15]. It is an ideal engineering material as its properties can be adjusted according to different requirements [16]. In south-east Asia, Parts of Africa and South America it has been traditionally used for long. The rural population of north-east India owns both supportive knowledge and skills to use bamboo as material. Since bamboo has major contribution in sustaining rural economy especially in the north-eastern states, this makes it an ideal choice to be considered for a design based intervention of micro energy systems in a local context with advantages like Eco-friendly, low cost, widely accessible and can support relevant local skills. It offers a great opportunity for micro and small scale enterprise development.

3 Social Construction of Design

Socially constructed design drives the development of a village in broader context. It signifies that design should not work in an isolation, but should rather address local issues by harnessing local resources, contributing positively to its social structure with ethical design. In order to perform as an ethical design, it should create a balance between environmental, economic and social sustainability.

Social context becomes critical in the propagation of design to rural grass root level as it combines commercial advantage with social and ecological profit. For design intervention to be socially responsive, it must embrace a framework of design that captures and delivers favorable social change.

This mutually cohesive methodology for design development can overcome existing barriers like lack of involvement of local stakeholders, technical inadequacy, a limited market, misperception about renewable energy in rural people and lack of work opportunities necessary for the dissemination of Solar PV Products and hence may result in a better market, local employment generation, and better social acceptance of design.

4 Design Based Rural Sustainable Development Framework

Proposed Design Framework can be used as a medium for sustainable development in the context of north-east India. This can integrate local development with promotion of Renewable Energy. As of now Solar PV products are seen as 'Tangible Devices' which has to be brought from external agencies to cater to the energy needs. In the present scenario it works in a very narrow buyer-seller context, resulting in many existing disadvantages. Renewable Energy interventions have the capability to integrate it with other development initiatives for people in rural societies. In this context, there is a prominent need for product design development framework.

This can bring newness to the idea at a system design level for micro energy devices like SHS, Pico PV, and Solar Lanterns. The idea of proposed framework is to support design intervention by making use of local materials along with local skills and resources resulting in local entrepreneurial opportunities and may strengthen local manufacturing capability.

Regional material like bamboo can be used to for the design development of Pico PV and Solar Lanterns. It will reduce/replace use of plastic as material and promote use of locally grown eco-friendly material. As rural communities in north-east India are traditionally skilled with bamboo so such design intervention can provide aesthetic and sustainable solution. Also, it will support subsidiary micro enterprises based on bamboo. In general, this may lead to upscaling of rural livelihood with multiple advantages as represented in Fig. 3.

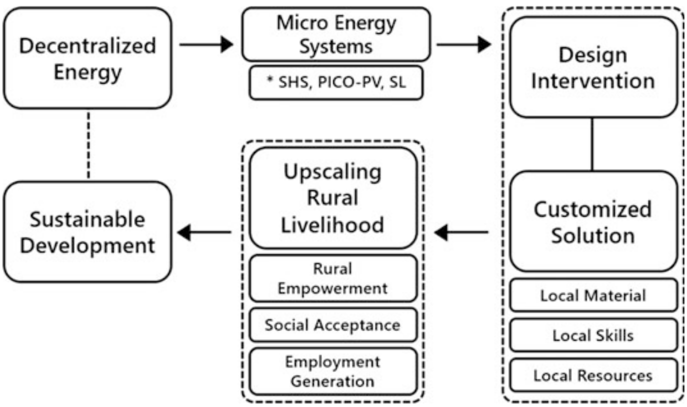


Fig. 3 Framework for rural sustainable development (*Source* Author Compilation)

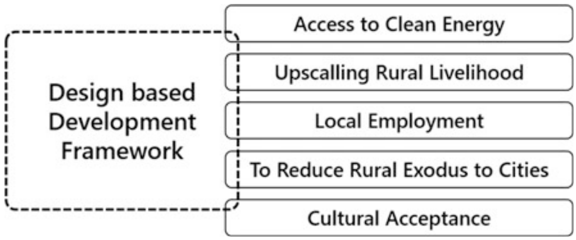


Fig. 4 Objective for design intervention (*Source* Author Compilation)

An integrated approach for designing micro energy system can provide 'Democratic Solution' for rural growth along with fulfilling basic energy requirements for homes as well as helps in creating small enterprise initiatives to upscale rural livelihood. This can be executed with help of rural self help groups.

The objective of a proposed framework (Fig. 4) is that modern energy can act as a catalyst for sustainable development. This enables the rural community to attain;

1. Access to clean energy addressing need for basic energy requirement and better connectivity to the wider world.
2. Generating opportunities for local employment by earning a viable living
3. Reducing rural exodus to urban areas, by giving them the choice between traditional route of migration to a city, or life in a developed Village.
4. Better Social acceptance of such products as they are perceived as part of culture.
5. Upscaling rural livelihood by providing better option to achieve their development potential.

Design based on rural sustainable development framework is vital to the economic, social and environmental viability of the region. There is great value to be gained, by integrating rural development initiatives that contribute to up-scaling sustainable livelihoods through efforts at the local, regional and national level, as appropriate. This Improves access to reliable and affordable energy, including renewable sources of energy for sustainable rural development. The framework can support rural stakeholders, especially women and local youths and can promote gender equality to achieve equal opportunities in all aspects of rural development.

5 Scope of Framework: Design Intervention Attempt

Framework-based design Intervention for micro solar energy devices fulfill the basic home electricity requirement and have portable off-grid applications like usage on Fishing boats or in fields. The resultant product can provide on-demand electricity to charge mobile phones and enable small businesses to operate under luminaire (Fig. 5). Also the same scope can be extended for other applications like PV panel stand.

Fig. 5 Design intervention prospects (*Source* Author Compilation)

Design intervention can assist in lowering daily kerosene consumption leading to safer and healthier life of a user also have socio-economic benefits like an extended study time for students, improved working hours for rural artisans, craftsmen, street vendors, etc. and the creation of better opportunities for local employment. Salient features of resultant design are Mobility, Ease of Usage, Basic load support, a detachable PV Panel (Fig. 6) Overall product will be Locally Resourced and Assembled.

The product can be easily assembled with the help of a local rural cluster group. The design integrates simple sub-assembly to locally resourced bamboo casing. This involves the use of techniques like bamboo molding for easy to

Fig. 6 Salient features (*Source* Author Compilation)

Fig. 7 Use of simple bamboo casing (*Source* Author Compilation)

produce shapes (Fig. 7) Bamboo can be given available industrial treatment to improve its longevity as material and to fulfill the design criteria.

Such products can create local opportunities and can be sold by rural entrepreneurs in coordination with NGO's or State Nodal Agencies or by Government Subsidized Shops 'Surya Kendra' selling solar energy based products also this may promote use of locally grown eco-friendly material.

6 Need for Energy Innovation: Prospective Scope

Increasing the stake of renewable energy is on priority in countries around the world, especially in developing countries. Clean, reliable energy would be a priority as it would not only mitigate huge emissions of greenhouse gasses, but also help millions of people with Social, Economic and Environmental benefits. It can unlock new economic opportunities, already growing. With falling prices, renewable energy technologies are fast becoming affordable especially Solar PV.

Given the scale of energy poverty for a country like India, one should be exploring potential avenues with renewable energy based design interventions. It could be one of the most appropriate solutions for the Self-Reliance of villages in India, in particular, the north east region. Access to energy reinforced with renewable energy based design interventions can address the range of existing issues for rural societies. Considering it's given benefits there is critical need for energy innovation.

7 Conclusion

Design based on rural sustainable development framework brings many advantages to promote social and economic benefits like micro-enterprise opportunities, Involvement of local stakeholders, use of local resources and design-led social innovation. This can be used as poverty reduction strategy not only in domestic scenario but also can be replicated by other developing countries with similar socio-economic context. It can help existing government policies in creating better social acceptance of solar PV products for the region. Design development should consider the fabrication using locally available material and skills. This may supplement lack of local manufacturing capability for north-east India and can also cut onto existing supply-chain/logistics costs.

The proposed framework provides new scope for renewable energy intervention at a system design level not seen as it is before. This may address energy poverty for the region and also serves resultant design in the broader context of rural development. The framework should initiate new knowledge for social construction of product design that brings economic, ecological and social profit to all.

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Design for Communities: An Entrepreneurial Approach to Solve the Problems of Society and Environment Fuelled by Product Design

Eshan Sadasivan, Mainak Das and Shantanu Bhattacharya

Abstract In an emerging economy like India, is it possible to solve the unique problems faced by people at the bottom of the pyramid by design and development of special products and services? Is it possible to build new eco-systems for wealth creation fuelled by a for-profit social enterprise with main focus on designing innovative products for society? Can new product design and development be the heart of a start-up social enterprise that is intending to empower people at the lower strata of our society? In this paper, the problem of pollution due to plastic carry bags has been discussed. The attempt towards design and development of a compact low cost paper carry bag making machine to mass produce eco-friendly and bio- degradable carry bags from recycled paper to replace the use of plastic carry bags by setting up many small scale industries throughout India to empower people has been described. This paper emphasizes on the challenges involved in designing innovative products of social importance and building a sustainable business model around the product along with creation of the eco-system required to empower the communities by taking the example of a start-up social enterprise.

Keywords Product design · Social entrepreneurship · Eco-Design · Design for sustainability · Plastic pollution · Sustainability driven entrepreneurship · Product innovation process · New ventures

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1 Introduction

Use and throw plastic carry bags are used extensively in our day to day lives and they are extremely environmentally unfriendly. These bags cause pollution and the only way to dispose them is through landfills [1]. Plastic bags are lethal and statistics show that at least 20,00,000 species of marine life forms, ground fauna and birds are annihilated every year because of choking or entanglement of plastics [2, 3]. The domestic animals accidentally chew plastic and get badly affected by infection and death. There are around 1 million fragments of light plastic floating as surface and sub-surface debris per square mile of the total surface area of oceans in a worldwide basis. Around 10^8 tons of plastic has accumulated as surface and subsurface debris over all oceans and this number doubles every three years [4].

Plastic does not dissolve; it breaks into tiny pieces and stays there for up to 1000 years, contaminating soil, waterways and oceans and entering the food web when eaten by animals [5]. At this size it is eaten by every single organism on the earth. Since the 1950s almost every piece of plastic that we have ever made, used and thrown away is still here on this planet and will be here for centuries to come. Thus the plastic bags are a really big menace for the earth and our environment. On the other hand, paper bags which promise to be the best possible alternatives face the problem of mass production as they involve time consuming processing and are mostly manually made. Thus they heavily lack in standardization and do not have dimensional consistency. Also, they may not be able to get produced in millions due to the process of production. Even banning of plastics bags by passing ordinances has seen no major light in terms of getting rid of them as need for carry bags drives manufacturers to sneak out their production of plastic bags and that is further being taken up very well by the local markets etc. [6]. So, many ideas of banning the plastic bags have completely failed as there is no alternative carry bag produced in mass.

2 Problem Identification

2.1 Plastic Pollution

Data collected across the globe over years reflect that there is an annual consumption of 500 billion carry bags and covers made up of plastic. Our society has a high consumption rate of plastics amounting to almost one million bags per minute consumption worldwide and this is a significant concern for the environmental health (Plastic bags world report—Clean Up Australia [7, 8]. India is one of the highest plastic consuming countries in the world. Yet, not many efforts have been made to recycle, re-use and dispose plastic waste. It may be argued that plastic waste can be recycled and reused. However when it comes to practise the reality is quite different. Actually the thin plastic bags are almost impossible to be fully

Fig. 1 Animals feeding on plastic bags (*Source* http://awfw.org/grants-animals/)

recycled and there is a possibility of incineration as a solution which may cause additional environmental damage. So, the state of most of these bags is their disposability after use in landfill sites. There is an abnormally high time scale that these may actually take in a landfill to actually fully degrade (around 300 years). Further it is common place scientific knowledge that they contaminate the soil and waterways by increasing the overall toxicity through an extract composed of tiny plastic particles which are non-easy to degrade further. These further gain an easy entry into the food chain. The food route provides a highly porous border for contaminants to transfer into intestines of animals chewing the contaminants along with other waste. Incidentally our nation also does not have an infrastructure in place for controlled animal husbandry and many a times the creatures are left to themselves to graze and consume insecure waste food for sustenance. Owing to these overall events they stand a high risk of mortality (Fig. 1).

Owing to this poor degradability of plastic bags they eventually end up travelling millions of miles every year through sewers and waterways to the oceans and this causes the pitiable, almost dumping ground like status of the oceans. There are other interconnected problems within OU Nation owing to the poor infrastructure of waste collection or waste disposal/recycling facilities. One of the problems is the interference with the water cycle by preventing seeping of ground water the subsurface water reserves thus jeopardizing the water table. Further there are many chemicals contained by these bags like cadmium or lead which may be labeled as serious health hazards by leaching into the contained food.

2.2 Ban on Plastic Bags

There has been many instances of administrative control of plastic carry bags and each country has a policy in place for this environmental menace [6]. The

Environment Ministry of India has given several directives from time to time including a controlled production of plastic bags to almost total embargo on production of plastic bag etc.

There has been legislative directives related to the use of 8 in. * 12 in. bags of 20 microns thickness. The ministry has also directed all State Governments to provide registration details of plastics manufacturing units for proper governance and administrative control.

2.3 Alternate Carry Bags

Paper carry bags as shown in Fig. 2 have promised to be the best possible alternative to the plastic carry bags and are also eco-friendly and bio-degradable in nature. Bags made out of newspapers, recycled papers or any kind of waste papers are called "**Tree-Free Bags**" or "**Eco Bags**". These kinds of bags are very reasonable in cost and hold the weight of around 1.250 kg. To carry more weight some improvements in the design of bag are necessary like a card board strip at the base, sturdy handle, double layered bag etc… [9, 21].

Now a days these kinds of bags are spreading widely around the world because of their own economic value, 'eco-friendly' and 'tree-free' tags associated.

But these bags face the problem of mass production. The existing machines to mass produce paper bags have the following drawbacks:

- Too large, occupy huge area (Fig. 3)
- Imported, too costly
- Require many people to operate
- Need of separate machines for creasing, folding and gluing the paper.

So, many ideas of banning the plastic bags have failed as there is no alternative carry bag produced in mass [10].

Hence there is a need to build a compact, low cost carry bag making machine to mass produce alternate carry bags to replace plastic carry bags.

Fig. 2 Paper carry bags

Fig. 3 Existing paper carry bag making machine: expensive, bulky and labour intensive (*Source* http://www.tradeindia.com)

3 User Research

3.1 In Detail Analysis of the Situation of Present Day Bag Makers

Once the problem of pollution due to plastic carry bags was defined and the drawbacks in the existing technologies to mass produce paper carry bags was identified, a detailed user study was conducted by interviewing many manual carry bag makers in 2 states: Karnataka and Uttar Pradesh. It was the suggestions of those carry bag makers to design a compact, low-cost paper carry bag making machine to solve their problems related to paper bag business.

Meanwhile there was an interaction with NGO named Society for Human Welfare and Environmental Furtherance [SHWEF] based at Bhopal, Madhya Pradesh. SHWEF has been working to empower the paper bag makers in Madhya Pradesh for the past 10 years. When the idea of a compact and low cost newspaper carry bag making machine was discussed with them, they supported it and shared the survey report of the expenditure and earnings of the bag makers of three villages near Bhopal, Madhya Pradesh [16].

The summary of note-worthy points obtained by the analysis of the survey report provided by SHWEF and the interviews conducted in many homes of manual carry bag makers is as follows:

i. **Number of hours spent in a day**: Paper bag making is a tedious and time consuming process. At present people involved in paper bag making spend 10–12 h a day to meet the market demand. Number of carry bags produced manually in 1 h is approximately 30–40.
ii. **Difficulties in sourcing raw materials**: Since in many places paper bags are made by women, they find it difficult to source raw materials such as newspapers and better quality adhesive [glue].

iii. **Difficulties in sourcing man power and child labour**: Some families which depend completely on paper bag business for livelihood, put their children also into work for extra income.
iv. **Market for the bags**: Currently paper carry bags are used by few stationary shops, hot chips/namkeen sellers, fruit sellers [seasonal requirement] and medical stores. Women making these bags are unable to find/explore new markets. The main reason being:

    a. Current bag quality and durability is very poor.
    b. Bag makers work independently and there is no co-ordination among them to improve the business.

v. **Insecurity in getting orders and meeting the demand**: All women involved in paper bag making work independently and hence it is difficult for them to get regular adequate orders throughout the year. They also face the fear of failing to meet the order deadline due to various factors like difficulties in sourcing raw materials and manpower. There is also insecurity about having steady and sufficient income from this business.
vi. **Low profit margin**: All the above factors result in low profit margin. After working for 10–12 h a day throughout the month, the bag makers earn hardly 2000–3000 Rupees per month.

The choices in design of a compact, low cost machine were dictated by the problems faced by the present day manual carry bag makers. The use of a machine reduces the number of tedious working hours in a day. The increased production rate of better quality carry bags solves the problem of low profit margin. The design of a supporting eco-system around the machine consisting of arrangements for regular supply of raw materials required for carry bag production. Having tie-up with retail outlets and local kirana stores for regular orders for the bags produced will solve other problems faced by the bag makers. Design of a supporting network built in collaboration with NGOs, Government organizations, and MFIs [Micro Finance Institutions] ensures the affordability of the machine by the needy bag makers from the bottom of the pyramid.

3.2 Market Requirement

After the problem identification and user interaction stages, the market exploration was made by analyzing the Indian market scenario.

India's retail industry has 92% of unorganized retail stores comprising of grocery stores, drug stores, stationary stores, hawker carts, kirana stores, weekly markets, namkeen/hot chips stores, vegetable mandis etc… Shopkeepers of 95% of these stores use plastic carry bags to pack the items.

Many Indian states are enforcing laws to ban the use of plastic carry bags and this will open up new markets for paper carry bags. In the present day scenario, throughout India people make paper carry bags in their homes by hand. The bags produced are of poor quality and have very limited markets. Good quality paper bags made from craft paper are produced in an established factory setup using costly, imported machines and large manpower. This clearly indicates that there is a demand for paper carry bags of different sizes and quality to be used in different shops to pack different items.

A noticeable feature of the demand for paper bags is that it is highly fragmented and underserved. There are many situations where paper bags can replace plastic bags which need to be explored.

3.3 Need Statement

Since the existing machines for producing paper carry bags are: Excessively large i.e., they occupy large area and are complex; Expensive and require many skilled people to operate; Use separate machine assemblies for creasing, folding and gluing the paper to produce a paper carry bag; the existence of a dire need to provide an improved paper bag manufacturing machine which is compact, cost effective and relieves labor intensity of workers was found out. This idea of design and development of a compact, low cost paper carry bag making machine was actually suggested by a group of carry bag makers during the interview to solve many problems involved in the present day manual paper carry bag production process. This led to the generation of need statement:

"To design and develop a compact, low cost carry bag making machine to mass produce eco-friendly and bio- degradable carry bags from recycled paper to replace the use of plastic carry bags by setting up many small scale industries throughout India to empower people."

4 Product and Eco-System Design and Development

In the initial stages, the project started as a student thesis project and gradually the need to have a business angle to support in taking the product into the market was realised. Figure 4 shows the line drawing of the machine being developed.

Over a period of two years, more than 15 versions/prototypes of the paper carry bag making machine have been designed and developed starting from the low fidelity prototypes to realize the working, 3D modelling and simulation for analysis and eventually managing to come up with a completely automated and working version of the carry bag making machine.

After each prototype/version of the carry bag making machine was being made, it was taken to the carry bag making women in Kanpur and their opinion on the version was taken as shown in Fig. 5. The insights gleaned by interacting with them were helpful to make improvements in the next version.

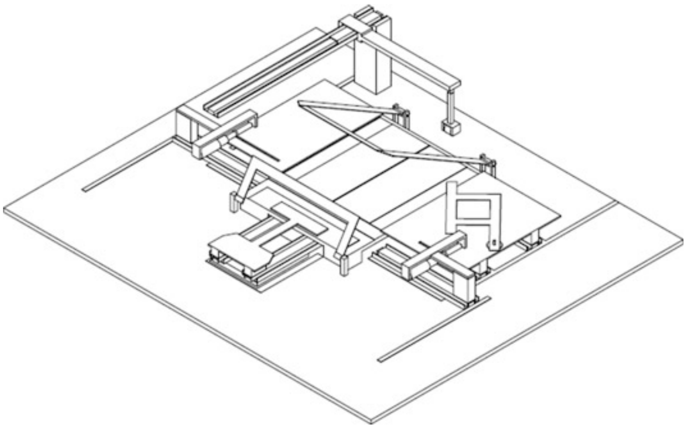

Fig. 4 Line drawing of the carry bag making machine being developed

Fig. 5 Explaining the kinematics of carry bag making machine to bag makers

An automated working prototype has been developed as shown in Fig. 6, and research is in progress to increase the quality and durability of paper bags produced. Business plan to take this innovation to the grass root level is being prepared [14, 19, 20].

The challenges faced during the process of taking a physical product into market to solve a social or environmental problem needs the utilization of a sustainable

Fig. 6 Present version of the completely automated paper carry bag making machine

business model and a proper supporting eco-system built around it [11–13]. To achieve this in a proper, efficient and professional manner a for-profit social enterprise has been incorporated as a Pvt. Ltd. company and incubated in one of the premier technical incubation centre of India. The four main challenges associated with building this for-profit start-up social enterprise are:

i. **Fund-raising**: In the initial stages, the source of funding for the development of prototypes and product realization was raised from the institute support, alumni donations and business plan competitions.

But after the company has been registered, to scale up things and increase the pace of operations efforts are in progress to reach out to start-up incubation centres, government grants and angel investor networks.

ii. **Product development and testing**: More than 15 improved versions of the carry bag making machine have been developed till date and it is assumed that at-least 6–7 more versions need to be developed and tested before the product is ready for market launch. Funding and team building are the critical factors to be concerned for achieving this.
iii. **Eco-system development**: A partnering mind-set to help build an eco-system required for the product to succeed in the market is essential to create the channel required for product launch. Collaboration activities with different NGOs, Micro Finance Institutions [MFIs] and Trusts active in the target market are in progress.
iv. **Order procurement and team building**: Order procurement for launching few of the initial pilot projects in different locations across India is being carried out and a dynamic team required to achieve all the above goals is being built.

5 Conclusions

The main objective behind the idea of designing this compact, low cost carry bag making machine is to enable the mass production of eco-friendly and bio-degradable carry bags in every small village/town so that this initiative may gel well with the local economy in India and thereby creating many employment opportunities on one hand and also eliminating the need for plastic bags throughout the country. The initiative can not only strengthen the local business ecosystem but also in a hidden way be responsible for the elimination of the plastic menace.

In a nutshell, the challenges involved in designing innovative products of social importance and building a sustainable business model around the product along with creation of the eco-system required to empower the communities involved by taking the example of a start-up social enterprise has been the primary discussion area of this paper [15, 17, 18].

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Supporting Social Innovation: Application of InDeate Tool for Sustainable Service Design—Case Study of Community Workshops

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Abstract Designing systems for sustainability involves satisfying diverse requirements spanning not just of the object of design but also of the designer, the context in which design happens and the design process. Taking an engineering design approach emphasizes the object of design as well as the process, albeit neglecting the designer and the context in which design happens. Taking a Gandhian approach to design necessarily emphasizes the designer and the context in which design happens, while the object of design could take a backstage. In this regard, this article applies the InDeate tool, developed to balance design approaches, for innovating a 'service design' for the community workshops of National Innovation Foundation (NIF). NIF is involved in supporting grassroots innovators and leverage their innovation for social and hence national benefit. On observing two comparable student groups conceptualizing for 'service design' with and without using the InDeate tool, as the variety of conceptual propositions is higher with the group using the tool, it is proposed that the tool could be a candidate for supporting design for social innovation.

Keywords Grassroots innovation · Service design · Social innovation · Lifecycle design · Design for sustainability

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1 Introduction

Design for Sustainability is arguably the grandest in the series of DfXs. The profile of requirements that need to be met cannot probably get wider than those necessary for sustaining human development. At the core of the concepts of sustainability, design, and hence, design for sustainability, lies a human-centric approach. Consequently, the importance for human development and designing for human development is foremost. As stated in the path-breaking World Commission on Environment and Development (WCED) report, "the limitations that prevailing social organizations impose on environmental resources can potentially impede the process of sustaining human development" [1]. This calls for innovating new forms of social organization that foster sustainability. As the iterative and empathetic nature of human-centric design process makes design central to innovation, it is appropriate to innovate social organizations by design. Efforts such as this could be categorized as social innovations. The Stanford Graduate School of business defines social innovation as, "…a novel solution to a social problem that is more effective, efficient, sustainable, or just than current solutions. The value created accrues primarily to society rather than to private individuals." One such example is the National Innovation Foundation's (NIF) endeavor to leverage creativity at the grassroots manifested in innovations that people without formal education come-up with ingeniously within available resources for the immediate benefit of the local community. NIF considers innovation central to driving national growth, and leveraging grassroots creativity assumes significance although its implementation faces challenges. As a methodical experiment that could potentially inform systematic support of social innovation, this research article reports the observations of using the InDeate tool for designing the services through the community workshops of NIF better. Due to its benefits to the immediate community, and the nation at large, this service design can be a social innovation.

The InDeate tool is a computer-based platform called InDeaTe—Innovation Design Database and Template, a tool for supporting the design-led innovation process, with two modules: a design process template, and a linked database with sustainability definitions, indicators, design methods and tools, for supporting designing of sustainable systems [2]. InDeaTe tool is a knowledge-driven sustainable design process support. It is meant to be a comprehensive yet generic tool to support innovation across domains of product, manufacturing and service systems. This research article reports the observations from applying the tool to innovate service design for NIF in the series of articles related to innovating for product, manufacturing and service systems. The tool is envisioned to be a web-based, user-friendly, open-source support, with a growing repository of information in its Database that can be used alongside the encompassing design process template.

With the objective of making India a leader in sustainable technologies and building a national register for grassroots innovations and outstanding traditional knowledge, NIF [3] works with the informal sector covering the entire gamut of activities from scouting and documentation of grassroots innovations and traditional knowledge, to their value addition, intellectual property protection, business development, social diffusion and commercialization. NIF is unique in supporting common people without formal education beyond secondary schooling and professional training who nevertheless could fathom technological solutions and implement them to avert problems in some measure without any external help. NIF has been able to build up a database of over 2,10,000 ideas, innovations and traditional knowledge practices (not all unique) from over 575 districts of India. NIF has filed over 725 patents (including 8 filed in the USA) in the name of the innovators and outstanding traditional knowledge holders of which 35 patents have been granted in India and 5 in the USA.

2 Problem Brief: Case Study of NIF Community Workshops

Most of the scouted grassroots innovations are at the level of rudimentary proof of concept, and the rate at which they are being converted to marketable products does not meet the demand for such products. In-order to increase this conversion rate, NIF is in the process of setting-up 37 community workshops (CW) located all over India with seasoned grassroots innovators who have distinguished themselves in their communities to be innovative problem solvers. The thinking behind having these CW is to facilitate innovators with decentralized manufacturing and scale-up of their grassroots innovations while also potentially familiarizing and inspiring local populations about technical problem solving and prototyping activities. It is hoped that through these CW more rural innovators would emerge to be ingenious in solve more local problems. These then could be taken up for refinement into making marketable products and scale-up, thereby contributing to national leadership in sustainable technologies. However, the adoption of the CW as a service design problem has not been thought out in detail, due to which their acceptability, use and potential impact thereby are hazy. As NIF perceives a national need for bold initiatives and new models for harnessing the creative potential of the society based on compassionate, caring, and sustainable models of development, the particular problem for this research article is to improve the service delivery through the CW by appropriate service design.

3 Design Exercise

Students distributed in two teams, who have not worked with NIF earlier either on the problem of service design for CW or anything else supplied by NIF, were tasked with suggesting improvements to the services at the CW.

3.1 Exercise Summary

The design exercise was conducted for approximately 16 h in June 2015 at Centre for Product Design and Manufacturing (CPDM), Indian Institute of Science (IISc), Bangalore, India, involved the following steps, two steps each per day with intermittent breaks:

- Introduction to the service design problem by an NIF representative
- Design exercise, conducted in two sessions per day, each with a distinct Student Design team as described below.
  Team 1: With InDeate Tool
  - A Ph.D. Student from IISc, working on Design for Sustainability, with background in Mechanical Engineering and Product Design;
  - A Ph.D. Student from UC Berkeley, working on Hydrogen fuel cells, with background in Mechanical Engineering;
  - A B.Tech student in Production Engineering from IIT Roorkee, India.
    Team 2: Without InDeate Tool (‘tool’ hereon, unless specified otherwise)
  - A Ph.D. Student from IISc, working in the area of Network-enabled Manufacturing, with background in Mechanical and Biomedical Engineering;
  - A Ph.D. Student from IIM Ahmedabad, working in the area of Water-Energy nexus for sustainability, with background in Environmental Engineering;
  - A Ph.D. Student from WSU, USA working in the research area of Life Cycle Assessment (LCA), with background in Mechanical Engineering;
  - A B.Tech student in Mechanical Engineering from IIT Ropar, India.
- Presentation of design outcomes to and feedback from NIF representative
- Assessment of improvement in service design (sustainability of it) with/without InDeate Tool.

3.2 Solution of Team 2 (Without Tool)

Team 2 started with the triple bottom line and identified design criteria within the three dimensions of sustainability as per the triple bottom line. Team 2 created flowchart as a method for understanding the service delivery better and identified objectives for the CW. Team 2 discussed ways to address the identified design criteria and meet the objectives and suggested improvements as listed against the criteria within the sustainability dimension.

Social dimension:

People in charge: Use the proven innovators for training new users on equipment.

Attracting innovators: Make people aware of the opportunity and generate excitement to use the CW by: displaying posters at public facilities that have last mile connectivity, like post offices and ration shops, govt. offices (*gram panchayat, tehsil* level, etc.) schools; advertising on radio, local newspapers, local cable news channels, and; hold competitions/exhibitions showing people what can be accomplished at CW.

Access to CW: Regionalize CW to ensure those in rural and remote areas have access to a CW; have a shuttle to ferry people to and fro to increase access to CW; provide an accessible road and encourage personal vehicles to ride-share towards the CW.

Occupational safety and health: Provide personal protective equipment and specific training to ensure everyone is safe working at CW; display safety information sheet at every CW equipment in relevant languages; ensure adequate fire extinguishers which are operational; mark emergency exits clearly; have first-aid kits handy; attaining an ISO 9001 certification could demonstrate that these good practices are in place.

Networking of Innovators: As increased external networking increases innovation [3]. an important way to increase innovation and help innovators create more successful, sustainable projects in the rural setting is to build a networking mechanism; Using a shared online sheet, which contains CW usage log information and is accessible by each CW, allows users to search for other who might be able to provide prompt advice; after such a system matures, other resources, such as experts from industry and academia, could be added to give innovators further contacts for networking and idea sharing and development.

Training on using equipment: Trainers other than the innovators could hold periodic training sessions on the CW machines; Employing female trainers might encourage more female innovators to use the CW;

Environmental dimension:

Waste management policy: Waste from CW should be disposed by proper methods; scrap from machining and other operations at CW should be collected and recycled; if scrap is large enough it may be fit for other projects and directly reused.

LCA for setup of CW: Lifecycle Assessment (LCA) could be done to determine eco-friendly choices of machines and building materials for the CW.

Source of power for CW: Renewable source, such as micro-hydro or solar power, should be used depending on location and availability of water and solar radiation; Life cycle-costing can be used to examine if that is also a cost effective strategy in the long-run, which could offset some operating costs for NIF down the road.

Economic dimension:

Sustainable funding: Develop sources of revenue to make the shops financially independent; make local industries pay to get their employees trained for certain skills at the CW; CW can conduct informal trainings for people who could not attend a vocational training institute (e.g. ITI); a percentage of royalty from successful innovations marketed has to be given back to the respective CW; make hand-tools free for use, but charge nominally for certain machines (CNC, lathe, etc).

3.3 Solution of Team 1 (Using InDeate Tool)

With the object of design now being the CW services, this interpretation as well as the process of designing the lifecycle of service is guided by the InDeate tool. Due to the limitations of time and resources, design process was limited till conceptual design stage. Following are the outcomes of applying the InDeate tool to CW service design:

Task Clarification: On interpreting the problem brief (Sect. 2) in the context of the lifecycle phases of the CW service, the tasks:

- *Material Extraction*: Irrelevant, as the object of design is intangible service
- *Manufacturing*: How best to involve as many people as possible to build CW?
- *Distribution*: How best to disseminate the CW services?
- *Use*: How to effectively use CW services to support grassroots innovation?
- *End of Life*: How can the CW service design be so that it could be replicated (reused multiple times) at multiple places (scaling-up)?

Using the lifecycle phases of the CW service and the tasks interpreted within them as cues, the team arrived at a list of possible stakeholders (Table 1) using brainstorming, as the method chosen for its simplicity amongst others suggested by the InDeate tool.

To ensure that the requirements of important stakeholders are met before meeting those from others, the following exercise was undertaken: the list of given requirements was assessed to understand if they were common to all stakeholders, or if not, for how many stakeholders it was common (Table 2); Requirements in bold in Table 2 are those that are common to most stakeholders. Weights were assigned to indicate the priority of the requirement (last column in Table 2) and to the stakeholders (last row in Table 2).

Table 2 shows that the innovator has a stake in most of the requirements followed by the users, trainers, funding agency and trainees. Therefore from the perspective of requirement satisfaction it was appropriate to use these weights normalized on a scale of ten while evaluating candidate concepts. However, if stakeholders needed to be prioritized in terms of mutual importance based on any other perspective, then a pair-wise comparison matrix could be made as suggested by the InDeate tool.

Table 1 List of stakeholders identified through brainstorming

Stakeholder	Identifier	Stakeholder	Identifier
Funders (NIF)	f	Trainees	te
Innovator	i	Users	u
People fearing failure (skeptics)	s	Government	g
Trainers	tr	Raw material suppliers	r
Machine builders	m	Local artisans	la

Table 2 Prioritizing stakeholders based on stake in requirements

List of requirements given	i	u	tr	f	te	g	m	la	s	r	
Provision for safe use of CW		1	1	1	1	1	1				**6**
Machine specific training	1	1	1		1		1				**5**
Repeatability	1		1	1	1	1					**5**
Provision for differently abled users	1	1		1					1		**4**
Affordability	1	1					1			1	**4**
Training for different age and gender groups		1	1	1	1						4
Cultural acceptability		1			1			1	1		**4**
To remove dependency on sophisticated manufacturing systems for building initial prototypes and prove out of built parts.			1			1	1	1			4
To promote the zeal of technopreneurship among the innovators	1			1		1			1		**4**
Provision for disposal of generated waste	1					1		1		1	4
In situ first level value addition research development support for creation of prototype (Proof of Concept) with the involvement of trained local fabricators			1		1			1			3
Joint product development with peer to peer learning and knowledge sharing	1		1		1						3
Setting up the enterprises and providing them basic technical support				1		1	1				3
Demonstration of technological innovations of grassroots innovators	1	1		1							3
End to End value creation and in situ Incubation	1	1									2
Expert opinion			1					1			2
Value addition in terms of testing, calibration, fine-tuning	1						1				2
To help convert ideas to prototypes at a very low cost		1									1
Prioritized stakeholders	**10**	**9**	**8**	**7**	**7**	6	6	5	3	2	

Conceptual Design of CW service of NIF: The conceptual design stage started with a concrete list of requirements, which are taken as the ones prioritized (in bold) in Table 2. Due to the limitations of time and resources available to the design group, the Team 1 conceptualized only for these. On laying out the prioritized stakeholders and list of requirements on the first column and first row of Table 3 (Part 1 and Part 2) respectively, cells at the intersection of any row and column are filled in, being empathetic to the stakeholder, suggesting ways in which the requirement could be met. These ways could be using existing products, processes and institutional systems as tools for meeting the requirement, suggesting modifications to them, or suggesting completely novel conceptions of meeting the requirement. On populating the matrix a combination of one or more conceptual solutions for meeting all the requirements could be chosen based on constraints at hand, thereby enabling Table 3 to be used as a morphological chart also. The priorities (weights, w) for the requirements and stakeholders could be multiplied as a first-estimate of the contribution of the social design in meeting that stakeholder requirement, within the overall conceptual solution combination within which all stakeholder requirements will have been variously met.

4 Discussion

The objective of this design research article is 'Service Design' specific to the community workshops of NIF and not the Service Delivery Model directly. However, because of the use of the InDeate tool, that imbibes a 'lifecycle design' perspective, to support 'Service Design', considerations beyond 'service design' in the service delivery lifecycle stated in the 'Service Delivery Framework/Model', i.e. service development, deployment, operation and retirement of services also happen to be attended to in the design process. For this reason it could argued that the outcomes of applying the tool as done here, indirectly address the innovation of Service Delivery Models or Frameworks. Akin to the product lifecycle, where design offers the best leverage to intervene into product development due to the fact that the design phase in the product lifecycle commits 80% of the invested cost and time of the overall product development [4], the service design phase in the lifecycle of the service, i.e. in the service delivery model/framework, offers the best leverage to intervene as the implications to infrastructure and associated people here could arguably be equal or more than with product design and development. Further, supporting design in the conceptualization phase of the service design process assumes significance and these processes are supported well by the InDeate tool as demonstrated in the results of this preliminary yet extensive design exercise.

Assessment of improvement in service design (sustainability of it) with/without InDeate Tool has been done comparing the variety of solutions i.e. number of dimensions across which the interventions could have also been thought about. It is observed that Team 1 has come up with a better variety of solutions in comparison with Team 2. From Table 3, over 50 conceptual solutions have been proposed

Table 3 Conceptual design suggestions for improving service design of CWs

Stakeholders	Requirements						
	Provision for safe use of CW (use) (w = 12)	Machine specific training (manuf.) (w = 7)	Repeatability (distr., EoL) (w = 6)	Affordability (distr.) (w = 10)	Accessibility for different age groups and gender (distr.) (w = 8)	Cultural acceptability (distr.) (w = 9)	To promote the zeal of technopreneurship among innovators (EoL) (w = 5)
Innovator (w = 8)	To be trained on machines/tools new to him and provide personal protective equipment	Ensures all innovator to complete all levels of training first, because innovators could lead by example	Geographically gauge requirements for similar innovation	Strategize to reduce consumable costs and running costs	Have dedicated dates of CW for differently abled and age groups, categorize aspect of innovation that involve users of different ages and groups for having separate slots/session	Imbibe cultural sensitivity into innovator (products innovations serving different needs of communities need to be manufactured in the CW)	Popularize innovators efforts across different CW (provide business training for innovators)
Users (w = 4)	To be trained on all tools and be provided training manuals and personal protective equipment	Ascertain competency and trainability of users	Communicate with relatives and friends about their involvement and benefit from CW	Provide instructions to use facility properly	Cater to demographics (have dedicated CW dates for differently abled and age groups)	(Products serving different needs of communities could be manufactured in the CW)	Train well and fast to work as an employee to the innovator

(continued)

Table 3 (continued)

Stakeholders	Requirements						
	Provision for safe use of CW (use) (w = 12)	Machine specific training (manuf.) (w = 7)	Repeatability (distr., EoL) (w = 6)	Affordability (distr.) (w = 10)	Accessibility for different age groups and gender (distr.) (w = 8)	Cultural acceptability (distr.) (w = 9)	To promote the zeal of technopreneurship among innovators (EoL) (w = 5)
Trainers (w = 6)	Provide personal protective equipment	Determine what comprises training levels for users and innovators	Developed easy-to-learn and follow training manuals	Development of training manuals should be economical	Flexible hours, after school hours, availability of trainers after school hours	Should be able to communicate in local language (situate CW at the border of state)	Train users and trainees to work fast
Funders (NIF) (w = 7)	Provide personal protective equipment	Skilled at negotiation in acquiring trainers as and when required	Standardize and improve pitch for CW model to the decision makers who approve funding	Strategize to reduce capital costs, cost of acquiring trainers, and trainers salaries (channelize CSR funds of banks towards high risk loans)	Bring in school involvement and pension funds	Source from religious group funds	Training on business basics, assistance with business model writing, foreseeing alternative uses of innovations, sourcing similar geographic requirements, disseminating and marketing innovations

(continued)

Table 3 (continued)

Stakeholders	Requirements						
	Provision for safe use of CW (use) (w = 12)	Machine specific training (manuf.) (w = 7)	Repeatability (distr., EoL) (w = 6)	Affordability (distr.) (w = 10)	Accessibility for different age groups and gender (distr.) (w = 8)	Cultural acceptability (distr.) (w = 9)	To promote the zeal of technopreneurship among innovators (EoL) (w = 5)
Trainees (w = 5)	Safety briefing, manuals, and personal protective equipment	Training levels should be to trainees' level of knowledge	Communicate to relatives, friends about involving and benefit from CW	Less time per trainee, facilities for training enmasse (collaborate with local community centres)	Incentivize probable trainees to take up work in CW (award academic credits students)	Have trainees from different communities mingle	Train fast and work efficiently under innovator

making it one and a half proposal per every systematic pair-wise comparison (cells in the table). From Sect. 3.2, it could be observed that Team 1 proposed approximately twice the number of ideas/concepts as Team 2. Though this does not conclusively establish the sole contribution of the tool, it could be considered a promising start which expands the options that can be considered for evaluation rather than to find oneself in a situation wherein an idea/concept has to be accepted due to their paucity. This is also reflected in the team members' responses to the questionnaire in two ways: first, members from a non-design background within the Team using the tool appreciated the design process aided by the tool commenting that if not for the tool and other members with a design background in their team they would not have contributed to the outcomes, and; second, members with or without design background in the Team that did not use the tool relatively appreciated their peers outcomes with the tool and the systematic and integrated lifecycle approach that the tool took. Assessment of improvement in service design (sustainability of it) with/without InDeate Tool has also been done based on consulting experienced people at NIF who have been involved in taking decisions regarding the implementation of the CWs, on whether the suggested improvements would be better in terms of the CWs fulfilling their purpose of establishment.

5 Summary and Future Work

In the context of assessing the benefits of using the InDeate tool for supporting 'service design', it was observed that during the first two stages of the design process the tool showed promise. The granular detail to which the process of design could be taken systematically provided more opportunities for generation of alternatives and their evaluation throughout the CW service's lifecycle design. The potential that the use of InDeate Tool for designing sustainable systems showed for the first two design stages could extend to the other stages too as the approach could use more methods that the tool and its database have to offer in supporting the design process as fitting to social innovation requirements. Conducting such work spanning the entire design cycle is work for the future.

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Reduction of Environmental Impact of Products Through Hotspot Analysis in LCA

Jitender and Prabir Sarkar

Abstract Substantial effort is made against the depletion of natural resources by designing sustainable products using Life Cycle Assessment (LCA) method. However, LCA does not indicate which unit manufacturing process has the highest opportunity for improvements with least resource allocation, that it where lies the hotspots. This study aims to find hotspots through LCA and help industries to identify the scopes for easy improvements. In this study, we consider 'water taps' manufactured by three companies and compute the Green House Gases (GHGs) emissions for each stage of a product, and find the lowest and average values of it. Next, we find the hotspots by comparing these values with the individual values of each process. Once hotspots are found, a company can focus only on these areas for fast reduction of GHGs. The practical effect would be reduction in carbon footprint, raw materials, energy, wastage of materials, and increase in economic benefit.

Keywords Life cycle assessment · Sustainability · Impact assessment · Hotspot analysis · Greenhouse gas emissions · Design for sustainability

1 Introduction

In recent years the growing concerns for ecological and climate change, together with concerns of poverty, increasing inequality between the public and the pressures brought by social inequalities, have positioned sustainable development under the spotlight. In reaction to the growing stresses coming from nationwide and worldwide protocols, and from public in general, corporations are increasingly pushed into the direction of accepting the values of both social and environmental responsibility within their strategies, structures and management systems [1, 2]. As

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addressed in recent studies on the very nature of sustainability, “any foreseeable sustainable state will be the result of interactions between organizations, individuals, societies and states” [3].

In a biosphere with restricted resource and severe environmental impressions, it is understandable that a more sustainable lifecycle style would be imperative [4]. So, the scientific research is shifted from environmental protection to sustainability. Sustainability is describe in 1987 by the world commission on environmental and development under the leadership of the former Norwegian Prime minster, Brundtland. Termed as ‘Sustainable Development,’ it is extensively discussed by eco-friendly policy researchers and non-governmental organizations (NGO), and it also appears within plenty of corporate assignment statements and Environmental charters, notably the Business Charter for Sustainable Development, which has been signed by over 1500 companies [5, 6]. The concept of Sustainability could be expressed as ‘Create from Silviculture’ which means that only as much wood is remove from the forests as grows again in the run [7]. Thus, Sustainable development is the development that meet the desires of present-day without compromising the ability of forthcoming generations to meet their own needs [8].

Sustainability in every area has a lot to do with “doing excellent with less,” and accepting a wider view of product development looking at the full lifecycle of the product and the impact that its design, manufacture, use, and end of life can have across the Triple Bottom Line (TBL) [9]. Often small changes may have large effects such as, selection of material may affect major changes in energy requirements and waste and end of life, [10]. It is an iterative process and not necessarily about new technologies by innovation and design. Sustainability, is also majorly associated with developing nations, which play vital role on a country’s economy and on the conditions and standard of living [11].

Life Cycle Assessment (LCA) has been extensively used in industries as a mean to reduce emissions and become more sustainable. By name it denotes the complete life of a product from “cradle to the grave”. It studies the movement not only of fresh resources, but also of fuel and energy to form something [9]. Regardless of certain boundaries, it essentially aims at making better informed decisions related to products and services in both business and policy [6]. LCA has also been used extensively in many specific areas such as, performance of carbon nanotube products [12], carbon footprint of bread [13], industrial milk production [14], and various cropping systems utilized for producing biofuels [15].

2 Phases of Life Cycle Assessment

Figure 1, shows LCA framework according to ISO 14040. LCA starts with finding the Goal and Scope Definition, where functional measuring units and material boundaries are identified. Next, during Inventory Analysis, inputs and outputs of materials and energies during the entire life cycle of a product are identifies, such as virgin resources used, discharges to the environment. In Impact Assessment, the

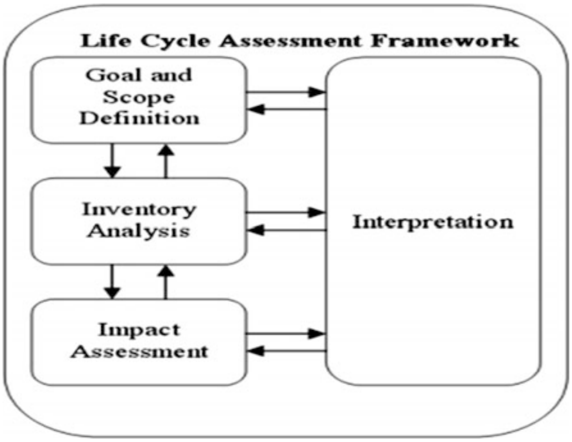

Fig. 1 LCA according to ISO 14040

consequences of the resource use and discharges produced are assembled and measured. During Interpretation, the results are reported in the most informative way and the needs and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically [16].

In this work our aim is to find out the hotspots through LCA. Past work such as, performance of carbon nanotube products [12], and carbon footprint of bread [13] and LCA of textiles [17], is restricted to finding out only the hotspot by applying the life cycle assessment method. Because there is no clear definition of hotspots or a clear methodology to find out the same, it is difficult to use hotspot analysis for any product. However, some research has similar approach. For instance, Product Carbon Footprint (PCF) analysis is used in German horticultural products like Strawberries, Asparagus, Roses and Orchids [18]. Similar research is used in sustainable food chains [19]. This available method tells us which process or step has how much amount of carbon emissions, in term of usage of excess amount of raw materials, energy, transportation, usage, end of life and services time period. However, LCA does not indicates which process or gate to gate process has capability to reduce the carbon emission. The method proposed here aims for this.

3 Goal and Scope Definition

The main purpose of this study is to reduce the CO2 equivalent with the help of LCA. So, for this study we consider small and micro scale manufacturing industries because 37% our country GDP is depend upon this type of sector. Also we are doing LCA within the company, which means we are considering only manufacturing process. i.e. gate to gate process. For this study we are consider three different companies which manufactured same components and product with almost same design.

4 Aim and Methodology

Our endeavor here is to find the hotspots through LCA analysis and help industries to identify the largest scopes for easy improvements and immediate reduction of GHGs with minimal resource allocation. The practical implication of this study is reduction of products' carbon footprint, reduction of the consumption of raw materials and energy, reduction of wastage of materials, and increase in economic benefit. For this study, we consider three different companies manufacturing similar products such as, a 'water tap.' We compute the greenhouse gas (GHG) emissions with the help of LCA for each stage of the product manufacturing by each company and compare them with each other to find the hotspots. Next, we find the lowest possible emission value for each life cycle stage by comparing values of each stage to all the products manufactured by the three companies. Additionally, we also find the values of the average GHGs emissions. For each stage of manufacturing, we find the difference between the GHG emissions/electricity usage against the minimum and average values of the same across all the companies for the same process. We attribute a hotspot when this difference is high. We sort these hotspots in descending order of values for each company as well as all the companies considered together. The recommendation is then, when a company has fewer resources (time, people, and money) to address and reduce GHG emissions, the company should first focus on the first hotspot, then the next, and so on.

5 Data Collection and Analysis

We collected data from three different companies, JAL, Regal and Essel. All of these three companies are manufacturing bathroom fittings and could be categorized under Small and Medium Scale Industries (SMEs). First, the first author went to these three different companies and met with their directors, who permitted the authors to collect data. The author then noted the components that all these three companies makes and found out the common components that are manufactured by all of them. One such component is the 'Wall mixer 32850' as shown in Fig. 2. This component is basically used to mix cold and hot water in different proportions. It is fitted just before the wash basin and after a geyser (water heater). Cold and hot water travels from the left and right portion of the Wall mixture and pass to the middle pipe, to the outlet. In the middle, a manual water controller is fitted (not shown in figure) which controls the relative amounts of different waters and allows passage of the mixed water to the wash basin.

For data collection, different instruments are used: A stop watch is used to note down the durations of activities, such as, time taken for melting of metal in a furnace, pouring time, machining time, testing time (leakage test by flowing high pressure water around 4 Pa, driven by a 3 HP motor), and time required for grinding, buffing, and electroplating. We used a camera to shoot the manufacturing

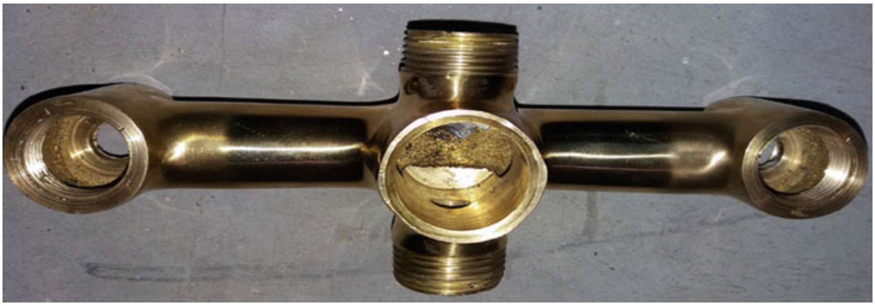

Fig. 2 Wall mixer 32850

steps. A dairy is used to note down the supply of quantity of raw materials and weight of the component after casting, machining, grinding and electroplating. Additionally, it is also use for noting down manually the energy consumption by different processes, computed based on the power rating of motors and from electric meters and duration of the operation. We had a Fluke™ energy meter with us, whose usage requires tapping the terminals to the motors' electrical connections. However, electrical connections in various machines were of concealed type and thus, it was difficult to set up this energy meter without stopping production. Thus, all calculations on energy consumption is based on the duration of an operation and power rating (Watt) of machines. We collected the data by monitoring each and every manufacturing step i.e. from allotment of raw material, machining process, grinding process and wastage that include material, sand and water.

Table 1, shows the data collected from three different companies following the process as described above. Power rating data is based on the motor ratings of each machine. Power consumption is computed by multiplying motor rating with duration of each operation. CO_2 equivalent is calculated by multiplying electrical power consumption with the average CO_2 equivalent due to the production of each unit of electricity which is 0.98 kg of CO_2 equivalent/KWH for India.

From Table 1, we see that the consumption of electricity during manufacturing of the same product is different for different companies. In fact, there are process level difference, that is, even though all the three companies are following the same process to manufacture the same component, they use different amount of electricity. Hence, the CO_2 equivalent is also different.

Next, we aim to find out how efficient each company's process is with respect to that of the other companies. Ideally, all should be able to attain the minimum GHG value for each stage, however, this might be difficult and resource intensive. Thus, we use average difference in our calculation. We consider the emissions generated by this company in respect to the average of others excluding the company analyzed (Eq. 1).

Table 1 Power consumption and CO_2 equivalent for manufacturing of component by JAL, REGEL and ESSEL

Process	Steps	Power ratings (kW)			Duration (min)			Power consumption (kWh)			CO_2 equivalent (kg)		
		JAL	REG-El	ESS-EL	JAL	REG-El	ESS-EL	JAL	REG-El	ESS-EL	JAL	REG-El	ESS-EL
Core making	Simple sand core	1.00	1.00	1.00	8.00	7.00	10.0	0.13	0.12	0.17	0.13	0.11	0.16
	Resin sand core	3.03	2.09	3.04	1.00	1.00	1.0	0.05	0.03	0.05	0.05	0.03	0.05
Total		4.03	3.09	4.04	9.00	8.00	11.0	0.60	0.15	0.22	0.18	0.15	0.21
Casting	Melting of raw material	40.00	285.17	40.00	1.00	1.00	1.0	0.67	4.75	0.67	0.65	13.93	0.65
	Pouring of material	60.00		60.00	1.00		1.0	1.00		1.00	0.98		0.98
Décoring	Fettling machine	3.73	0.00	2.98	60.00	0.00	60.0	3.73	0.00	2.98	3.65	0.00	2.92
Total		103.73	285.17	102.98	62.00	1.00	62.0	5.40	4.75	4.65	5.29	13.93	4.56
Rough grinding	Belt grinding	3.73	1.49	3.73	1.00	2.00	1.0	0.06	0.05	0.06	0.06	0.05	0.06
Machining	Lathe	3.73	2.24	3.73	6.00	5.00	6.0	0.37	0.19	0.37	0.37	0.18	0.37
	Capstan	5.96	5.97	5.97	2.00	1.00	1.0	0.20	0.09	0.10	0.19	0.10	0.10
Testing	Leakage testing	3.73	2.24	3.73	2.00	2.00	1.0	0.12	0.07	0.06	0.12	0.07	0.06
Grinding	Flat belt grinder	3.73	2.24	3.73	10.00	8.00	10.0	0.62	0.30	0.62	0.61	0.60	0.61
Polishing	Buff grinder	2.24	2.24	2.98	5.00	5.00	4.0	0.19	0.19	0.20	0.18	0.18	0.19
Total		23.12	16.41	2.98	26.00	23.0	4.0	1.57	0.88	0.20	1.53	1.18	0.19
Electroplating	Sk-40+ water	1.00	2.00	2.00	0.08	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00
	Ni-S + Ni-Cl + bon-ic acid + B-rihgter	1.49	4.00	4.00	20.00	20.0	20.0	0.50	1.33	1.33	0.49	1.31	1.31
	EC-94 + water	1.00	1.00	1.00	0.08	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00
	Cleaning	0.00	1.00	0.50	0.00	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Total		3.49	8.00	7.50	20.00	20.08	20.08	0.50	1.00	1.33	0.48	1.31	1.31

(continued)

Table 1 (continued)

Process	Steps	Power ratings (kW)			Duration (min)			Power consumption (kWh)			CO_2 equivalent (kg)		
		JAL	REG-El	ESS-EL	JAL	REG-El	ESS-EL	JAL	REG-El	ESS-EL	JAL	REG-El	ESS-EL
Packaging	L D Bags	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Polythene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total			0	0.00		0	0.00	0.00	0	0.00	0.00	0	0.00
Total		109.36	312.67	108.38							7.09	16.26	7.67

Table 2 GHGs for manufacturing of component by JAL, REGEL and ESSEL

CO_2 equivalent (Kg) per process			
Process	JAL	REGEL	ESSEL
Core making	2.78	−39.28	23.8
Casting	−69.01	63.99	−112
Machining	16.01	−23.72	2.51
Electroplating	−167.34	31.29	31.29

$$X_{iAvg.} = \frac{\left(Xi - \left(\frac{\sum_{i=1}^{i=X} \mathrm{Xi} - \mathrm{Xi}}{\mathrm{n}-1}\right)\right)}{Xi} \tag{1}$$

where $X_{iAvg.}$, X_i and n are 'average value of carbon emission of different process,' 'value of carbon emission of a process' and 'number of process' respectively. By using this above formula, a score for each process in each company is calculated and on the basis of this score the process are ordered as shown in Table 2. Thus, we try to assess how each company is performing with respect to other companies in each process or stage of manufacturing of a component, here, 'Wall mixer 32850.' For example Essel received 23.8 in core making as a score by using the above equation as:

$$X_i = 0.21, \quad \sum_{i=1}^{i=X} \mathrm{Xi} = 0.54, \ \mathrm{n} = 3 \quad \text{and} \quad \mathrm{Xi}_{Avg} = 23.8$$

6 Discussion

After doing analysis of each process of product life cycle of three different companies, we find out the hotspots in different section. In the first process i.e. in core making process, Essel consume highest amount of energy for core making (Sand core and resin coated) and emit large amount of GHGs. And on the same time, Regel consume lowest of energy as compare to other.

In the second process i.e. in casting process, Regel consume highest amount of energy and emit huge amount of GHGs as compare to two other as well as in whole manufacturing process of three different company. If we replace coke Owen (as used by Regal currently) with induction furnace (as used by other companies) the consumption of energy would decrease drastically in melting and pouring section. In this study, we find out some companies use scrap material and some use pure virgin material as raw material for product manufacturing. The problem is during melting of scarp material some time lead and sulphur also get melted with him which is already present within the scrap due to this whole melting lot is waste. These wastage leads to wastage of electricity, generation of GHGs as well as economic lose.

Table 3 Arrangement of manufacturing process according to highest GHGs (Hotspot)

Company	Process	Hotspots
Regel	Casting	63.99
Regel	Electroplating	31.29
Essel	Electroplating	31.29
Essel	Core making	23.8
Jal	Machining	16.01
Jal	Core making	2.78
Essel	Machining	2.51
Regel	Machining	−23.72
Regel	Core making	−39.28
Jal	Casting	−69.01
Essel	Casting	−112
Jal	Electroplating	−167.34

In the third process i.e.in machining process, Jal consume highest amount of energy and emit huge amount of GHGs. Similarly Regel consume least amount of energy and emit least amount of GHGs. In machining of product JAL consume heights amount of energy and produce highest amount of carbon dioxide/or GHGs. As a possible remedy, if 2.24 KW of motor for testing and grinding, then they produce enough pressure to check any leakage under higher pressure condition and 2.24 KW of motor is enough for grinding of same product for same time period.

In electroplating Regel consume large amount of energy and also emit large amount of GHGs especially in Nickel plating section as compare to other two. Reason behind this is that they didn't know how much power rating of motor is required for filtration and shaking. And in assemble and packaging section they use approximately same amount of manual power and energy. By using above formula, the GHG score for each process for each company is calculated and on the basis of this score the process are ordered as shown in Table 2. On this basis we arrange the processes priority wise with respect to largest carbon emission (hotspot) in Table 3.

7 Conclusion

Sustainability is an important issue for designers. Designers and companies are always in search for ways to reduce carbon emissions. However, reduction of carbon emissions requires spending of resources and allocating of time of many people. If we consider the entire life cycle of a product, there always exists many ways to reduce the environmental impact of products. However, not all possible routes are the same. Reduction of environmental impact in certain life cycle step would require a large expenditure of resources while for other, it may be fewer resources intensive. One of the ways to know if one possible route is fewer resources intensive (or difficult to achieve) or more resources intensive (or easy to achieve) is to find out by comparing the same with the process that is followed by many other companies who are manufacturing the same product. In this work we selected a component of a product (water tap) which is being manufactured by three different companies. We studied the life cycle energy expenditure for each stage of manufacturing the component of each company. Thus, we find out the average and minimum energy required for manufacturing this component. This stage also provides an indication on the performance of each company for each stage of the component manufacturing and the hot spots for easy improvements. The assumption is that if once company could practically manufacture the same component with less energy intensive process in one stage of manufacturing, the other company should be able to do the same easily.

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Koti Banal Architecture of Uttarakhand: Indigenous Realities and Community Involvement

Smriti Saraswat and Gautam Mayuresh

Abstract 'Koti Banal' architecture of Uttarakhand is a reflection of indigenous realities and community involvement. It demonstrates a profound knowledge of local materials and native sensibilities. Investigations suggest that this is an earthquake-safe construction style done in timber and stone, which evolved as early as 1000 years ago. This paper is an attempt to study the Koti Banal architecture of Uttarakhand and understand the craft nurtured by the indigenous communities using locally available materials in response to earthquakes. In fact, the Koti Banal architecture is much like the framed construction of modern times. The structural design suggests that these buildings responded well to the forces likely to act upon them during an earthquake. The paper further investigates what are the modifications that have happened in this style of architecture with respect to morphology and materials, through three case studies done in the Garhwal region. This is primarily a descriptive research based on a case study (field study) approach, which focuses on traditional knowledge systems; indigenous building materials; community involvement; and, craft skills of Uttarakhand.

Keywords Koti banal architecture · Uttarakhand · Indigenous · Craft · Materials · Community · India

1 Introduction

The state of Uttarakhand is known for its unique architecture known as Koti Banal style of architecture. According to the Housing Report on Timber Reinforced Stone Masonry given by the World Housing Encyclopedia (an initiative of Earthquake Engineering Research Institute and International Association for Earthquake Engineering), Koti Banal is the name of a village in the Yamuna Valley. This village employs traditional knowledge systems of construction, which are very

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scientific and earthquake resistant. Existing literature suggests that such architectural style evolved as early as 1000 years before present [1]. Koti Banal architecture did not depend on any building codes and recommendations. At the time of its origin, concepts of science and earthquake resistance were beyond the thought process of people. Despite all these odds the designs of the multistoried houses seem to follow the present day building codes of earthquake safety. Noticeable amongst the earthquake safety characteristics of these houses are—form and proportion; small and single entrance; and, joinery details. Many of the buildings belonging to this style of architecture have proved to be long-lasting as much as 200–300 years (even more in few cases). Such examples highlight traditional knowledge systems; indigenous building materials; community involvement; and, craft skills. Major earthquake resistant properties and characteristics observed in Koti Banal architecture are:

(a) *Building Plan and Massing:* the houses constructed in Koti Banal style are symmetrical about the axis, have simple rectangular shapes and enclosed areas, which respond better to earthquakes. Structure is simple in details and has no or very little ornamentation that is limited to carvings in wooden members and does not negatively affect the seismic performance of the structure. Multiple unit houses made in this style have interconnecting walls along the smaller axis. These interconnecting walls behave like a rigid box improving the earthquake resistance properties. The height of these houses is usually 7–12 m above the base. The traditional houses usually have five storeys. Some of the key features of these houses include a simple layout of the structure; construction on an elaborate, solid and raised platform; incorporation of wooden beams all through the height of the building at regular intervals; small openings and shear walls.
(b) *Choice of Site*: stability of slope and selection of firm ground have been key criteria in for construction from seismic point of view.
(c) *Ductility, Deformability and Damageability*: ductility and deformability are the important attributes of seismic resistant architecture. They allow structure to undergo large deformation without collapsing. Damageability is another attribute, which allows structure to undergo substantial damages without partial or total collapse.
(d) *Choice of Materials*: locally available wood and stone were used for this type of construction. Wood is a ductile material and stone is a brittle material. Addition of wooden reinforcement to stone masonry improves the tensile property of structure. Extensive use of locally available wood was made in these homes since wood is an elasto-plastic material with the ability to absorb the brunt of an earthquake.

Studies show that this construction style has been predominantly found in the northern part of the state Uttarakhand, and the similar adaptations have been in practice in many other parts of India as well few other neighbouring countries. The Field studies bring forth that this style of architecture can be seen in three forms currently:

(a) Original Style; (b) Modified Style; (c) Original Morphology, but New Materials

Existing researches and field studies done by the authors suggest that Koti Banal is relevant in contemporary times. But, it needs modifications (discussed later).

1.1 Research Queries and Investigation

There are two queries, which are fundamental to this research:

(a) What is Koti Banal style of Architecture?
(b) Is it still in practice?

1.2 Methodology

Methodology for this research employed the following steps:

(a) Information and understanding on the Koti Banal style of architecture was gathered through Historiography.
(b) A conceptual framework was formulated that emphasized on the inter-relationship between—Koti Banal; traditional knowledge systems; indigenous building materials; and, community involvement.
(c) Detailed on-field research was carried in the selected villages of the Garhwal region—Malari, Gainchwan and Purola (only Malari discussed in detail). This research involved participatory approach as well as on-field observations by the authors, to develop a comprehensive understanding of the varied cases of the Koti Banal construction, followed in the selected villages.
(d) Analysis was done, and inferences were drawn.

1.3 Conceptual Framework

There are four major aspects that go in the formulation of the conceptual framework of this research:

(a) *The paper takes into account the vernacular nature of construction in Uttarakhand*: any construction may be called as vernacular if its style relates to, or is specific to the region or surrounding culture [2]. The houses in the villages of Uttarakhand reflect an agrarian lifestyle; belief systems and way of life; and, the resources provided by the surrounding forests. Many houses still follow the Koti Banal style, but others have transitioned into an international style, which utilizes concrete, brick and other new materials (easier to build). "The loss of such vernacular houses and the increase of nondescript concrete styles can transition a distinctive cultural landscape into one that is more mundane, or placeless" [3]. Koti Banal style of construction is indeed vernacular in nature and holds values that need to be celebrated and preserved.

(b) *Indigenous Materials play an important role in creating a unique identity*: the term indigenous means 'originating in and characteristic of a particular region or country'. Indigenous architecture may be explained as 'native science of building', and involves working with a community having certain skill sets. Uttarakhand developed its own style of architecture and a unique identity based on abundantly available materials—wood and stone.

(c) *Community Involvement and Crafts*: the communities have been involved in the construction processes, since times immemorial, and continue to do so. Making of the house highlights the harmony with nature. The auspicious motifs and carvings reflect the craft skills of its inhabitants. They render an individualized characteristic and a visible cultural identity to their houses. These decorative elements could play a role in the endurance of vernacular landscapes even today, amidst modernization. Their house is also the key to understand their culture and social order. The craft practices, especially wood carvings and *aepan* paintings are the narratives of their belief systems, way of life, everyday happenings and climate concerns. Repetitive motifs and paintings within a house and amongst other houses make cultural significance more likely.

(d) *Tradition and Continuity hold keys to sustained practices and culture*: The continuity ensures the existence of traditions, but with modifications; alterations; adaptations, which are pretty much required for growth. The modified Koti Banal architecture and the aspirations of the communities are a testimony to this. The knowledge and skills get transferred empirically from one generation to the other, and continue to sustain the culture. Case studies helped in determining the essential qualities that allow a vernacular style to represent a cultural group, play a role in place-making, and accept change in a meaningful way. Geographic isolation "insulates" residents and "reinforces their dependence on what they know and have inherited," sustaining "truly indigenous examples" and unbroken traditions of architecture ([4], 56; [5], 163). This is partly because "a narrow range of material choices determine[s] the architectural language" ([6], 327), meaning that fewer options for building materials and limited exposure to alternate designs encourage repetition of traditional ways. However, very few places are without outside influence today.

2 Literature Review

The State of Uttarakhand falls in seismically highly sensitive zone. As a response, it has evolved a very unique style of architecture called as Koti Banal, which has been prevalent since almost thousand years. The radiocarbon dates show that the principles of earthquake safety had evolved in the region quite early. The detailing suggests that those designing the structures had a fairly good idea of the forces acting upon the structure during an earthquake event [7]. Koti Banal style of architecture is a human response to the seismic disturbances in nature, utilizing the potential of the local resources and community knowledge. Based upon experience, explorations, empirical knowledge and ingenious skills, human populations around the globe have evolved innovative practices for ensuring survival against all odds. Communities residing in hilly areas are often affected by earthquakes. They were quick to understand the fundamental premise of earthquake safety that the key to avoiding loss of human lives lies in ensuring safe construction. This fundamental understanding led to the evolution of koti banal architecture, which ensured safety from structural collapse. The alacrity to protect the community, by utilising traditional knowledge systems and experimenting with locally available building materials, paved the way for the evolution of a unique architectural style that exhibits structural evolution trends whereby dry stone masonry, as also stone–lime/mud/clay mortar masonry was judiciously used with wood to provide appropriate strength and flexibility to the structures.

The house was generally composed of the alternate bands of dressed timber and stone rocks that were tied at corners through interesting joinery. The structure was further reinforced with the help of wooden beams fixed alternately, that run from the middle of the walls on one side to the other; intersecting at the centre. “This arrangement divided the building into four parts and provided for joists supporting the floorboards in each floor of the building” [7]. The top floors were flanked by balconies enclosed within wooden railings. Different floors were connected with timber ladders, which were often scooped out of a monolithic tree trunk using hand skills. The roof was composed of the *patthal* (local stones), which were supported over wooden framework.

These structures used wood in huge amount both for construction and ornamentation. Like the RCC frame of present day multi-storied construction, the Koti Banal architecture used wooden frame for the entire structure. The voids were filled with rocks (local stones). “These walls took the vertical load; while the interconnected wooden joists running in both directions took the horizontal load” [7]. To enhance the seismic performance, two beams running across from opposite directions were placed from outside. The structure was raised on a platform two to four meters above ground. The stone-filled solid platform kept the centre of gravity and centre of mass of the building closer to each other and near the ground. This mitigated the overturning effect from the tall structure and protected it during earthquakes.

Tying of walls at corners and by providing horizontal bands at critical levels such as the lintel levels to ensure that individual walls do not suffer out of pane failure due to seismic forces during earthquake, which is commonly the reason for roofs to collapse eventually [7]. The bands can be provided in timber (including bamboo splits) or reinforced concrete and structural connections between basic elements of a building—foundation, walls, columns and floor slab/roof should be such so as to allow safe transfer of the inertia forces generated by the earthquake through the different elements, by imparting the required ductility to them. While the floor slabs and beams receive due attention, it's mostly the vertical elements such as walls and columns which fail under the stress and cause damage to the building. The overall shape, size and geometry of a building play a critical role in performance during earthquakes. Simple plans with structurally correct distribution of columns and walls behave the best and irregular shapes have the highest risk of twisting during earthquake and subsequent damage. Particularly, in case of rural non-engineered buildings built with local materials, it is critical to ensure that commonly used materials like stone and bricks are suitably reinforced to increase their resistance to earthquakes [8].

The basement of these houses, locally termed 'Goth' was meant to house the cattle. It had a single door opening in the courtyard. *Goth* was connected to the first floor through a wooden staircase and lid. This lid was used to attend the cattle during the winters, without going through the snow-covered chilled courtyard. The lid kept slightly open also facilitated carrying the heat generated from the cattle to the upper floors. This was a science that the local community applied for keeping the house warm. The higher floors were made of timber covered with clay (local *khar* soil at many places). Wood also acted as an insulator. Wooden beams and breakers also acted as shock absorbers.

Koti Banal Structure also display hand crafted ladders and carved motifs. Carvings and motifs suggest a clear link between temple design and domestic architecture. The carvings are more prominent in Kumaun than Garhwal. These craft forms impart distinctiveness to these structures and also a cultural identity.

The Koti Banal style of architecture needs to be studied and documented in detail. The traditional knowledge systems embedded within this style would new possibilities of exploring the community-oriented sustainable practices that have survived the tests of time and proven eco-friendly. Most of the houses belonging to this style are disappearing due to challenges of frequent maintenance and concerns for comfort. If these issues could be addressed, the houses could continue to flourish with necessary modifications. The disassembled building materials from these houses are being used for construction of new and modern dwellings. Foremost, the community has to be made aware about the issues of protecting these heritage structures to enable the coming generations to have a glimpse of the architectural traditions of this region. This would also provide researchers with an opportunity to study this architectural style of Uttarakhand in detail, and carry experiments to establish its relevance in contemporary times.

3 Detailed Study of the Selected Cases: Malari, Gainchwan and Purola Villages, Uttarakhand

Detailed field studies were conducted in few villages of the Garhwal Region of the Uttarakhand. Village Malari (discussed majorly here) situated in the Dhauli Ganga valley of the Nanda Devi Biosphere reserve is a small village near the Tibet border (Figs. 1, 2, 3, 4, 5, 6 and 7). With a population of approximately 900, the main inhabitants of the village are the *Bhotia* Tribe. The inhabitants of Malari, resides the place from the months of April to November. During other months, they come to lower altitudes due to hard living conditions. The main source of livelihood in this place is cattle rearing and agriculture. Malari is one of the UNSECO's World Heritage Sites. Most structures in village are more than 200 years old and typically follow the Koti Banal style of architecture or its adaptations. Main building materials that have been used in these structures are stone, timber (Deodar: *Cedrus deodara*; Chir: *Pinus roxburghii*; Toona: *Toona sinensis*), khar soil and lentils as mortar. Khar soil possesses excellent binding capacity and has also been extensively used for plastering. This village follows the koti banal style of architecture in its most original form, and all the construction is done by the community itself.

Village Gainchwan also follows similar examples. Gainchwan situated in Mori block of Uttarkashi district is a small village with a population of approximately 800 with over 180 households. The main sources of livelihood are cattle rearing and agriculture. Most structures in village are more than 100 years old and typically follow the same architectural style. Building materials mainly used in these structure are stone, Timber (Deodar: Cedrus deodara; Chir: Pinus roxburghii; Kail: Pinus wallichiana) and Chikani Mitti (Clay soil) as mortar. Clay soil is also extensively used for plastering.

Village Purola (Figs. 8 and 9) exhibits a construction, which uses new construction materials yet retaining basic architectural style of the region.

Discussing Village Malari in detail, the prominent characteristics of this style observed during the documentation are:

Fig. 1 Village Malari

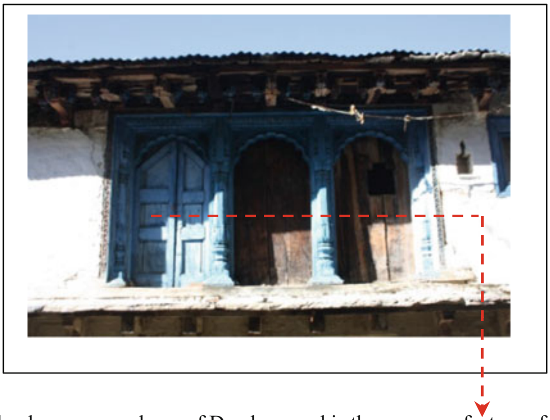

Fig. 2 Openings on upper floor of front facade

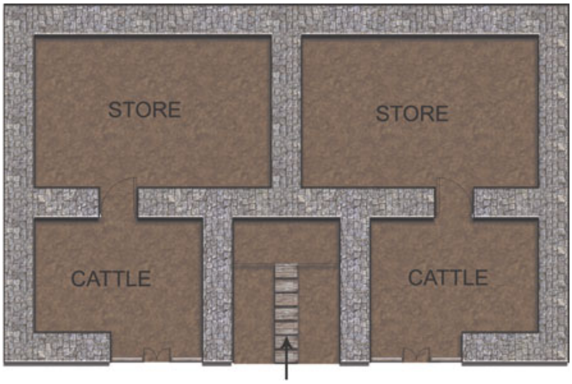

Fig. 3 Ground floor plan

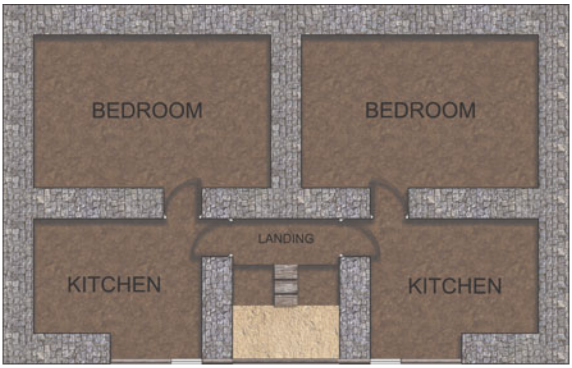

Fig. 4 First floor plan

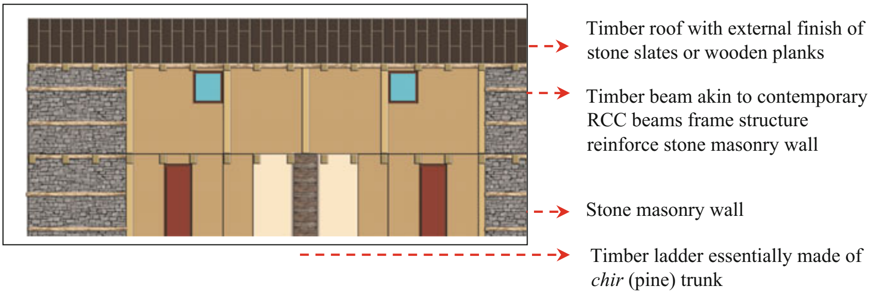

Fig. 5 Front elevation

Fig. 6 Commodities of a typical house—utilitarian craft practiced by the community and Kitchen

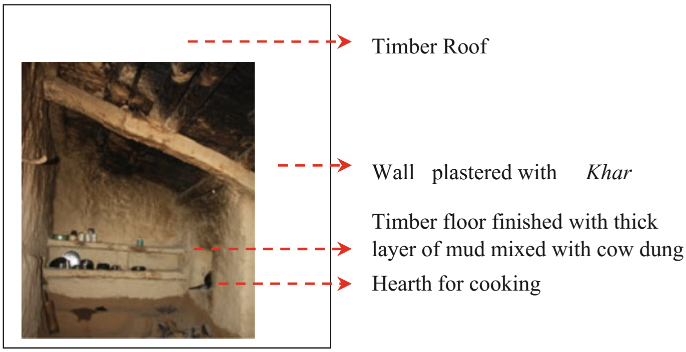

Fig. 7 Craft practiced by the community and kitchen

Fig. 8 On-going contemporary construction in typical Koti banal style of architecture in village Purola

Fig. 9 On-going contemporary construction in typical Koti banal style of architecture in village Purola

i. Simple layout with liner geometry
ii. Construction on elaborate, solid and raised platform
iii. Judicious use of indigenous building materials—stone and timber
iv. Incorporation of wooden beams all through the height of the building at regular intervals, thus giving it structural stability
v. Small Openings for climatic concerns
vi. Shear Walls to take care of the lateral forces and the seismic disturbances
vii. Low embodied energy because in principle this construction uses only locally available materials.

The structures studied have simple rectangular plans. They have a raised platform, having length and width ratio between 5 and 9 m. The two sides of the structures follow ratio between 1.1 and 1.4. The structures are symmetrical both with respect to mass and rigidity, so as to minimize torsion and stress concentration. Such designs ensure earthquake resistance. First the wooden frame of the structure is kept in place and then the voids are filled with stones. This is similar to the framed construction of modern day, taking care of both the vertical and the horizontal load. The height of the platform varies between 2 and 4 m (as suggested by the existing literature also) above the ground and dry stone masonry is used for its construction. The platform at the base is very crucial as it ensures keeping the centre of gravity in close proximity to the centre of mass, and also near the ground. The enclosing four walls could be seen as alternate courses of timber and stone. Further reinforcement is achieved through the wooden beams that run from the middle of the walls on one side to the other, intersecting at the centre. The structures studied are meant for a single-family house. These buildings have only one main entrance at ground floor level above the foundation platform. The access to upper floors is solely provided by wooden ladders, hand crafted out of a monolithic wooden trunk. All the studied built forms exhibit the craftsmanship of the community involved. The interior spaces as well the exteriors are the live examples of the craft skills and the tacit knowledge of the communities. The kitchen and the living demonstrate the use of *ringal* and weaving crafts, which are exquisitely used for the day-to-day needs. Few wood carvings are also seen in the houses, which are used as embellishments, and celebrate life.

3.1 Observations and Inferences

Koti Banal style of architecture has tremendous potential for incorporating the design and construction principles into contemporary buildings. This style of construction demonstrated some of the basic principles of earthquake safe construction. Moreover, it involved community participation; their ingenious skills; knowledge of local resources; and, indigenous building materials. The Koti Banal architecture, however, did not cater to the comfort of the inhabitants. This was perhaps responsible for the introduction of aberrations in the original construction style. Specific to the cases studied, the village Malari follows the most crude and the original form of the Koti Banal style of architecture. Village Gainchwan has few modifications as per the changing needs of the community. But, the morphology still remains the same. In village Purola, the building materials are contemporary. But, the style used for construction is Koti Banal itself.

Current construction practices in hills of Uttarakhand are influenced and driven by various factors including loss of traditional knowledge systems; non-availability of skilled craftspersons; introduction of modern construction materials like cement; market strategies and government policies. This has led to the adoption of architectural style, commonly found in plains and not indigenous to hills.

3.2 Conclusion

The changes that have taken place in the Koti Banal style of architecture are reflections of social and environmental changes that have taken place in the society. They indicate that it is not easy to hold on to the construction techniques and the historic vernacular forms, due to the contemporary aspirations. The macro level components—materials for building, methods of construction, and the form of house—are particularly vulnerable to the mentioned changes. They are strongly impacted by resource availability and market dynamics (current trends; supply-demand), aspects that are beyond the control of the community. The macro level changes in interior-architecture have brought long lasting changes in the life of the community. Also, the continuity of vernacular traditions is threatened. Changes at this level have large-scale impacts on its appearance (for example, the disappearing *goth,* which has been so integral to the house form and the lifestyle). Cumulative changes like this multiply, and alter drastically the innate character of the cultural landscape of the settlement. However, having expressed the above, there is still a presence of the “Koti Banal” style. It is at least clear that the style has not been completely abandoned; few selected aspects have been modified to address changes in building materials and lifestyle. The community is holding on to the spirit of Koti Banal through sustained day-to-day life events; practices of incorporating micro level components such as decorative features; and, through continued social activities in the common spaces. There is a need to delve into new materials with the old principles of structural design and community involvement, which Koti Banal style embraced. It will ensure a landscape that continues to reflect the identity of the community and also takes care of new aspirations. Since, the local skills will get employed; it will also lead to opportunities for culturally sustainable livelihoods and enterprises resulting in additional benefits to the local economy. Moreover, the local crafts like the *ringal* craft; wood carvings and the weaving can also be integrated in creating utilitarian and lively spaces. It is also suggested that the Government should ensure that the new constructions proposed, should respect the existing built forms and maintain the unique identity of the state.

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Assessment of GRIHA and LEED on the Parameters of Sustainable Design and Development of Buildings

Shiva Ji, Sharmistha Banerjee and Ravi Mokashi Punekar

Abstract To practice design for sustainability in the domain of Building Design, Construction and Usage, we require Sustainability Assessment (SA) Methods, Tools and Techniques; which suggest pre-design as well as post completion checks to assess impact in terms of material and energy consumption, environment, society and economics. GRIHA and LEED are the leading SA methods currently in use in India. Since they originate from different countries with different contexts, level of technology and type of usage, they possess some degree of distinction over the other. A need was felt to gather these methods and discuss so that clarity can be drawn upon the scope defined by them to address sustainability. The objective of this paper is to analysis the chosen SA methods and evaluate their scope in terms of sustainability using the three pillars of sustainable development: *Social*, *Economic*, *Environmental*. A literature review based evaluation of methods was conducted. From the analysis, it is evident that both the tools are targeting towards *Sustainable Buildings* but the criteria list of GRIHA still lay more emphasis on the *Environmental* and Economic pillar and less on the *Social* pillar. LEED has good emphasis across all the three pillars. The paper ends with suggestions on a list of social, cultural and socio-economic criteria which can be added to GRIHA for further strengthening it on the *Social* pillar.

Keywords Design for sustainability · Building sustainability assessment methods · GRIHA · LEED

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1 Introduction

The United Nations World Commission on Environment and Development, in 1987 chaired by [1] Gro Har-lem Brundtland, former Prime Minister of Norway, issued a report, "Our Common Future". The report defined sustainable development (SD) and is the most accepted definition of SD today. It says SD is "a form of development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [1]. In the context of architectural design, sustainability and SD have been an area of concern due to many factors. Chwieduk, Dorota say that the energy consumption by buildings is huge as compared to other sectors [2]. Though it varies from country to country but overall it's around 30–40% of total global energy demand. Hence many authors like [3] emphasis on the need for due consideration to external as well as local contextual factors relevant to a site, using which a more sustainable building and its constituent should be designed and constructed. Other architects like Charles Korrea have given a huge emphasis on study of local elements and cultural living contexts and designing built environment accordingly. Architects like Laurie Baker have laid a great emphasis on environmental and economic sustainability through low cost techniques and building material. Auroville has been doing a lot of research on environment-friendly living methods and architectural design but not necessarily low cost. Thus there are very few examples of architects or researchers who could work on all the three verticals of SD, i.e., social-environmental-economic, in the context of built environment design, construction and usage.

Berardi [4] and Martens [5] states that the sustainable building definitions are often complex, unclear and are hence difficult to implement. They usually begin defining sustainable development as opposite of non-sustainable development [5] or "doing less harm" [6]. Thus the paper targets to compare the existing building assessment techniques like LEED and GRIHA against SD parameters and highlight the departures and gaps.

1.1 Sustainability Assessment Method 1—Leadership in Energy and Environmental Design (LEED)

LEED is a third-party certification program for design, operation and construction of green buildings. It rates different types of buildings on the basis of its environmental compatibility, capacity to provide a healthy surroundings for its occupants and profitability for the stakeholders. It started as an independent initiative by US Green Building Council in 1998 as a measure for evaluation and assessment of different types of buildings. Broadly it developed formats to cover various typologies of buildings (New Construction, Core and Shell, Schools, Retail: New Construction and Major Renovations, Healthcare, Commercial Interiors, Existing Buildings: Operations and Maintenance, Neighborhood Development, Homes) and released some country specific editions (USA, Australia, Canada, Bazil) too. The system has evolved over the years and currently version 4, released in 2013 is in use.

LEED presents an integrative process which has three stages:

1. Discovery: It's a pre-design stage which guides design process for optimum design delivery post construction. It lays thoughts, guidelines and recommendations before schematic design begins.
2. Design and construction: This includes interaction of all entities and their inter-relationships. It caters to the effective outcome of the all entities as a system.
3. Occupancy, operations and performance feedback: It works for measuring performance and integrates system for feedback loop.

Performance in LEED are measured along the following parameters:

1. Energy Performance
2. Water Performance
3. Indoor Environmental Quality
4. Sustainable Sites
5. Materials and Resources Performance
6. Innovation in Design.

The parameters defined in the framework provide detailed checklist for the buildings industries that are measurable and quantifiable in credits points. The LEED structure is designed to incentivize progressively higher credit achievement and in turn progressively higher compliance with credits whose outcomes accomplish the system goals.

1.2 Sustainability Assessment Method 2—Green Rating for Integrated Habitat Assessment (GRIHA)

GRIHA is an evaluation tool launched in 2007 in India to help design, build, operate, and maintain a resource-efficient built environment. It was developed jointly by Ministry of New and Renewable Energy, Government of India and The Energy and Resources Institute (TERI) [7], New Delhi.

[As GRIHA preamble quotes] GRIHA in Sanskrit means 'Abode', it's the interaction of human habitat in the lap of nature. GRIHA attempts to minimize carbon footprint, emissions and other impacts on environment. Its criteria measure the quantified values of major aspects of evaluation and in a way proposes guidelines for high rating measures. The GRIHA initiative is being followed by various development agencies throughout the country now and is picking up amongst Architects, Engineers and Construction companies. GRIHA is widening its reach by conducting training programs and subsequent exams for certifying professional evaluators and assessors.

For the ease of application and project assessments, it has been divided into three versions based on scale of projects. It starts from self-evaluation version to big scale projects which require longer and in-depth evaluation.

GRIHA presents an integrative process which has three stages:

1. Pre-construction stage: (intra- and inter-site issues like proximity to public transport, type of soil, kind of land, where the property is located, the flora and fauna on the land before construction activity starts, the natural landscape and land features).
2. Building planning and construction stages: (issues of resource conservation and reduction in resource demand, resource utilization efficiency, resource recovery and reuse, and provisions for occupant health and well-being). The prime resources that are considered in this section are land, water, energy, air, and green cover.
3. Building operation and maintenance stage: (issues of operation and maintenance of building systems and processes, monitoring and recording of energy consumption, and occupant health and well-being, and also issues that affect the global and local environment).

Performance in GRIHA are measured along the following parameters:

1. Project Scope
2. Site Planning
3. Innovation and Design
4. Indoor Air Quality
5. Material
6. Energy Efficiency
7. Water Efficiency
8. Facilities and Services.

1.3 The "Dialectical Systems Approach" for Sustainable Building

Researchers who have used system approaches and methodologies to examine Sustainable Buildings; argue that all stakeholders and their inter-relationships have a role in overall improvements [8]. Edum-Fotwe and Price [9] gave three categories for categorizing sustainable urban environments: "those which represent *spatial scales*, urban systems and *development life cycles*, and *sustainability dimensions* and their associated issues and sub-issues, such as stakeholders, impact, influences and polices associated with any entity". Bozicnik and Mulej [10] defines dialectical systems as "enabling humans to apply the law of requisite holism to their observation, perception, thinking, emotional and spiritual life, decision making, and action". The requirement of the system in totality is because it provides middle path between unrealistic total sustainable system and total loss system.

All these theories try to define the sustainability in built environments and give some specific points to build upon the framework. These are the building blocks of the larger inclusive definition.

1.4 Built Environment Shapes Collective Development

As quoted by Ching [3]: "The basic elements, systems and orders that constitute a piece of architecture; all are the constituents of a design work and can be perceived and experienced through. Any system gets its interrelationship through these and a formal form, shape and size … Architecture is generally conceived—designed—and realized—built—in response to an existing set of conditions. These conditions may be purely functional in nature, or they may also reflect in varying degrees the social, political, and economic climate. In any case, it is assumed that the existing set of conditions the problem is less than satisfactory and that a new set of conditions a solution would be desirable. The act of creating architecture, then, is a problem solving or design process".

The above definition clearly elaborates the integrity of various elements of building design and built environment, their roles with respect to others, and as a whole it tries to satisfy the needs at political, social, economical and environmental levels and thus serves tremendous scope for the collective development and thus, SD.

2 Methodology

An analysis of the parameters of LEED and GRIHA against the three pillars of SD, social-economic-environmental, was conducted. All data used was gathered using GRIHA and LEED explanatory documents. The paper uses *GRIHA v2015* and *LEED v4 for BD + C: New Construction and Major Renovation*.

Each criteria from the above GRIHA and LEED rating system was mapped to target *Environmental*, *Social* and/or *Economic* pillar of SD definition. Health related criteria and other criteria which implied direct involvement of human stakeholders (occupants and service providers) and their well-being has been marked under social. For example, under LEED, one of the sub-criteria is light pollution reduction, defined as "To increase night sky access, improve nighttime visibility, and reduce the consequences of development for wildlife and people". This definition indicates a direct impact on human health and well-being and hence has been marked on Social pillar. Also it has a direct impact on the health and well-being of wildlife and hence marked on the Environmental pillar. The impact on Economic pillar is indirect and as a consequence of the impact on Social and Environmental pillar. Hence the Economic pillar has not been marked.

3 Results and Discussions

Table 1 presents the analysis of *GRIHA v2015* and *LEED v4 for BD + C: New Construction and Major Renovation* criteria on the three pillars of Sustainability. From the table, following aspects are evident:

1. GRIHA has a strong focus on Environmental and Economic aspects. The stress on the Social is less evident.
2. LEED on the other hand has more balanced focus on all the three pillars.
3. GRIHA has a dedicated section for assessment of socio-economic aspects of the laborers and service professionals, creating awareness on environment and design for accessibility. This aspect is missing from LEED.
4. LEED has social aspects like open space access, bicycle facilities, diversity in use and quality views included in its assessment. These can become interesting additions to GRIHA matrix as well.
5. LEED has a section dedicated to *Regional Priority: Specific Credit* wherein region specific sustainability parameters can be assessed and credits earned. Incorporating this feature in GRIHA will further enhance the assessment tool's applicability over diverse Indian contexts.
6. Edum-Fotwe and Price's [9] three categories for categorizing sustainable urban environments on the basis of *spatial scales*, *urban systems* and *development life cycles*, and its relationship to *sustainability dimensions* have also not been captured well in the current GRIHA tool.

4 Conclusion Further Work

As per Alwaer and Clements-Croome's [11], energy-efficient buildings only center its attention around one aspect of it, i.e., energy consumption. Green buildings on the other hand are environment-friendly buildings but they do not consider all aspects of SD. Considering the impact of buildings, [2] presented the following typology for the buildings:

- Energy-efficient buildings;
- Environmentally-friendly buildings;
- Sustainable buildings.

The analysis presented in Table 1 indicates that both LEED and GRIHA are designed to match the third typology i.e. *Sustainable Buildings.* GRIHA currently

Table 1 Analysis of GRIHA v2015 and LEED v4 for BD + C: New construction and major renovation criteria on the three pillars of sustainability

	GRIHA v2015: List of criteria and rating structure			**SD criteria catered to**			**LEED v4 for BD+C: new construction and major renovation**			**SD criteria catered to**		
	Criteria No.	**GRIHA criteria**	**Points**	**Environmental**	**Social**	**Economic**	**Criteria No.**	**LEED criteria**	**Points**	**Environmental**	**Social**	**Economic**
	Group 1	**Site planning**	**8**				**Group 1**	**Location and transportation**	**16**			
	1	Site selection	1	✓			2	Sensitive land protection	1	✓		
	2	Low-impact design	4	✓			3	High priority site	2	✓		
	3	Design to mitigate urban heat island effect	2	✓			4	Surrounding density and diverse uses	5		✓	
	4	Site imperviousness factor	1	✓			5	Access to quality transit	5	✓	✓	✓
	Group 2	**Construction management**	**9**				6	Bicycle facilities	1	✓	✓	✓
	5	Air and water pollution control	1	✓			7	Reduced parking footprint	1	✓		
	6	Preserve and protect landscape during construction	4	✓			8	Green vehicles	1	✓		✓
Site Selection and construction Phase related criteria	7	Construction management practices	4	✓		✓	**Group 2**	**Sustainable sites**	**10**			
							9	Construction activity pollution prevention	Required	✓		
							10	Site assessment	1	✓	✓	
							11	Site development – Protect or restore habitat	2	✓		
							12	Open space	1		✓	
							13	Rainwater management	3	✓		
							14	Heat island reduction	2	✓		
							15	Light pollution reduction	1	✓	✓	
							16	Construction activity pollution prevention	Required	✓	✓	
	Group 5	**Water**	**17**				**Group 3**	**Water efficiency**	**11**			
	14	Use of low-flow fixtures and systems	4	✓		✓	17	Outdoor water use reduction	Required	✓		
	15	Reducing landscape water demand	4	✓		✓	18	Indoor water use reduction	Required	✓		✓
Water	16	Water quality	2	✓	✓		19	Building-level water Metering	Required	✓		✓
	17	On-site water reuse	5	✓		✓	20	Outdoor water use reduction	2	✓		
	18	Rainwater recharge	2	✓		✓	21	Indoor water use Reduction	6	✓		✓
							22	Cooling tower water use	2	✓		✓
							23	Water metering	1	✓		✓
	Group 3	**Energy**	**20**				**Group 4**	**Energy and atmosphere**	**33**			
	8	Energy efficiency	13	✓		✓	24	Fundamental commissioning and verification	Required	✓		✓
	9	Renewable energy utilization	7	✓		✓	25	Minimum Energy Performance	Required	✓		✓
	10	Zero ozone depletion Potential materials	0	✓			26	Building-level energy metering	Required	✓		✓
							27	Fundamental Refrigerant Management	Required	✓		
Energy							28	Enhanced commissioning	6			✓
							29	Optimize energy performance	18	✓		✓
							30	Advanced energy metering	1	✓		✓
							31	Demand response	2	✓		✓
							32	Renewable energy production	3	✓		✓
							33	Enhanced refrigerant management	1	✓		
							34	Green power and carbon offsets	2	✓		✓

(continued)

	Group 6	**Sustainable building materials**	**14**				**Group 5**	**Materials and resources**	**13**			
	19	Utilization of BIS recommended waste materials in building structure	6	✓		✓	35	Storage and collection of recyclables	Required	✓		✓
	20	Reduction in embodied energy of building structure	4	✓		✓	36	Construction and demolition waste management planning	Required	✓		
	21	Use of low-environmental impact materials in building interiors	4	✓			37	Building life-cycle impact reduction	5	✓		
Materials and Waste Management							38	Building product disclosure and optimization – environmental Product eeclarations	2			
	Group 7	**Solid waste management**	**6**				**39**	Building product disclosure and optimization – sourcing of raw materials	2			
	22	Avoided post-construction landfill	4	✓	✓		**40**	Building product disclosure and optimization – material ingredients	2			
	23	Treat organic waste on site	2	✓	✓	✓	**41**	Construction and demolition waste management	2	✓		
	Group 4	**Occupant comfort and well being**	**12**				**Group 6**	**Indoor environmental quality**	**16**			
	11	Achieving indoor comfort requirements (visual/thermal/acoustic)	6		✓		42	Minimum indoor air quality performance	Required		✓	
	12	Maintaining good indoor air quality	4	✓	✓		43	Environmental tobacco smoke control	Required		✓	
	13	Use of low-volatile organic compound paints and other compounds in building interiors	2	✓	✓		44	Enhanced indoor air quality strategies	2		✓	
							45	Low-emitting materials	3	✓	✓	
Health and Well-being	**Group 8**	**Socio-economic strategies**	**6**				46	Construction indoor air quality management plan	1			
	24	Labour safety and sanitation	1		✓		47	Indoor air quality assessment	2			
	25	Design for universal accessibility	2		✓		48	Thermal comfort	1		✓	
	26	Dedicated facilities for service staff	2		✓		49	Interior lighting	2		✓	
	27	Increase in environmental awareness	1		✓		50	Daylight	3	✓	✓	✓
							51	Quality views	1		✓	
							52	Acoustic performance	1		✓	
Contextualisation							**Group 8**	**Regional priority**	**4**			
							55	Regional priority: specific credit	1	✓	✓	
							56	Regional priority: specific credit	1	✓	✓	
							56	Regional priority: specific credit	1	✓	✓	
							57	Regional priority: specific credit	1	✓	✓	
	Group 9	**Performance monitoring and validation**	**12**									
Performance	28	Smart metering and monitoring	8			✓						
	29	Operation, maintenance protocols	0									
	30	Performance assessment for final rating	0									
	Group 10	**Innovation**	**4**				**Group 7**	**Innovation**	**6**			
Innovation	31	Innovation	4				53	Innovation	5			
							54	LEED accredited professional	1			
	Total	**Total score**	**104**				**Total**	**Possible total points**	**110**			

Note Bold is used for highlighting categories within SA methods matches more with the *Environmentally-friendly Building* typology. Hence, addition of the following dimensions is suggested to bring GRIHA closer to *Sustainable Building* typology:

Social Aspects

- Site assessment from a social perspective
- Availability of open spaces
- Availability or ease of access to public transport, schools, healthcare, shopping and related amenities
- Design for encouragement of social interaction
- Design for encouragement of social cohesion
- Innovation in connecting *spatial scales*, *urban systems* and *development life cycles*, and its relationship to *sustainability dimensions*
- Design for well-being
    - Thermal
    - Lighting—daylight and interior/exterior lighting
    - Visual
    - Acoustic

Cultural Aspects

- Influence of architectural design on cultural aspects of the region or population on aspects like history, geography, heritage, symbols, art, cultural practices or beliefs, etc.

Socio-Economic Aspects

- Surrounding density and diverse use based assessment
- Lifecycle analysis, performance costing and cost to the people—on their livelihood, health, recreation, education.

Other dimensions suggested to be incorporated in GRIHA are as follows:

- Demolition waste management
- Possibility to integrate Green Vehicles/walking
- Construction activity pollution and accident hazard prevention
- Site development considering protection/restoration of habitat
- Building material sourcing disclosure
- Regional priority specific credits

5 Further Work

The scope of the study was limited to analysing the various parameters of LEED and GRIHA as mentioned in the matrix document against the three pillars of SD. In future analysis of various design contexts and the suitability of LEED and GRIHA can be undertaken. This combined with the analysis presented in this paper can give a rich information on how can we further enrich the GRIHA and LEED parameters for varied Indian contexts.

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A Concept for Assessing Sustainability—The Sustainability Diamond

Daniel Kammerl, Roland Zink, Christoph Hollauer and Udo Lindemann

Abstract The paper presents a new assessment methodology to measure sustainability for product development. The sustainability diamond consists of three dimensions, six criteria at the intersection of sustainability and usage and a variable number of indicators. Furthermore the concept provides opportunities to integrate people and actors (stakeholder) as well as a dynamic aspect, which gives the user the ability to apply the concept to different topics.

Keywords Sustainability assessment · Sustainability indicators

1 Introduction

Although sustainability is showing its age, the current adoption of the resolution "Transforming our world: the 2030 Agenda for Sustainable Development" on September 2015 [1] by the General Assembly as well as the United Nations conference on climate change on November 2015 in Paris (COP21, http://www.cop21.gouv.fr/en/) reflect the persistently high importance of the guiding principle. Rather, the term "transformation" calls for a permanent adaption and search for best solutions, in order to meet sustainable development. Despite these political and social anchorages, there is still a gap in the application of the guiding principle in

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the daily behavior of people, policy decisions and also economic activities. Consequently, the adopted 17 objectives set out a vision that applies to implement it in the coming years.

Motivated by this state of affairs the present paper represents a concept for the operationalization of sustainability in product development. Starting from the basic concept of sustainable development and embedded in a 3-level model of product development, an assessment system will be introduced, which presented a measurement hierarchy with dimensions, criteria and indicators. At the same time the assessment system provides opportunities ready to integrate people and actors through a weighting in the evaluation, making it also receives a participatory character. This aspect is essential, since modern integrative sustainability concepts are dependent on such a Stakeholder engagement by the union of different dimensions or interests.

Especially consumer industry has a great impact on implementing sustainability. Many companies consider sustainable economic activities as investment in the own future ability, because it offers new business opportunities. Hence, sustainable action is a long-term business case and has a permanent positive effect on the success of a company. Under these circumstances the consideration of the whole product life cycle is of high importance. In particular the use phase can offer a great potential for improving the overall product sustainability.

2 Sustainability for Product Development

Although the term sustainability has been established in science and everyday life, the content and especially the operationalization of the basic idea remain controversial. For that matter, the core of the definitional discussion is the question of prioritizing the content. This fact is becoming very clear when comparing the radical concepts of strong and weak sustainability. The main difference identified by Döring and Ott [2] is the divergent assessment of substituting natural capital. Strong sustainability demands a constant basic stock of natural capital over time [3]. Weak sustainability allows the substitution of natural capital for real capital infinitely, as long as the average use and welfare are maintained [4].

These two extremes haven't proven expedient in practice despite their theoretical coherence [5]. On the one hand [6] determined, that there are more than those two opposed points of view when discussing strong and weak sustainability. On the other hand the today's concept of sustainability includes at least the three dimensions of ecology, economy and social affairs. Thus, sustainability conceptually is designed for compromise and not for radical positions. This view especially is reflected in the so-called 'three-pillar model' [7] in which the three dimensions are considered to be equal and coordinate, interact with each other and require a long-term balanced coordination [8]. In industrial context mostly the equality is not granted and the triple bottom line—originating business sciences—is applied, where social and environmental aspects are only taken into account when making balances. To compensate on that [9] propose the triple top line, where improvements in the environmental and social sector shall be pursued, which are economical profitable at the same time.

When further developing those multi-dimensional concepts ‘integrative sustainability’ as the so-called HGF-approach was established [10–12]. This approach aims at reclaiming the normative premises of sustainability deduced from the der Brundtland report [13] and the Rio-declaration “Agenda 21” [14. Hence, constitutive elements of sustainability are justice (inter and intra generational), globalism and anthropocentrism [10, 15].

In the context of this article sustainability is defined according to the Brundtland report the ambition to fulfil the needs of today’s generation without taking this possibility from future generations [13]. Based on this understanding of sustainability, for product development we define it as following:

To develop a sustainable product, a multidimensional dynamic process has to be taken into account, which includes the aspects of at least the three dimensions ecologic, economic and social aspects. Thus we refer sustainability not to the development or production process but to the product itself. The aim of sustainable product development is to meet the customer needs considering social and ecologic constraints and at the same time generating economic value for the company. A sustainable product induces additional value for company and customer without alloying economic and social quality alongside the whole product lifecycle.

3 State of the Art

In this section we describe the Framework for sustainable product development which was presented as a concept by Kammerl et al. [16]. The system of indicators shall serve as basis for the goal definition and the assessment of the resulting product. In Sect. 4 we present a regulatory scheme focusing on all three pillars of sustainability and especially taking into account the use phase. The indicators were taken from [17] focusing on environment and [18] taking into account all three pillars of sustainability.

Framework for sustainable product development [16] Each planning phase of the development cycle starts with the consideration of the entire system and the definition of strategic problem-fields (problem layer) on the abstract problem-layer (see Fig. 1).

On the basis of this problem definition, specific sustainability-goals are formulated within the goal-layer (goal layer). Therefore, the desired sustainability-characteristics are chosen from a list of different criteria and their desired characteristics are specified. As every sustainability-property may be achieved by certain methods and design principles, the goal layer also specifies the operative activities. The respective methods are applied on the action-layer and thus, in this layer the

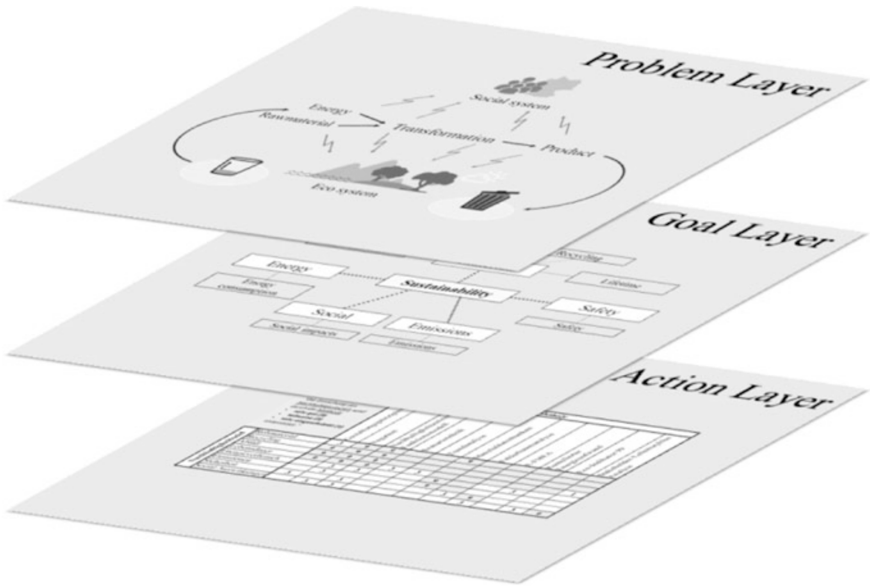

Fig. 1 Framework for sustainable product development according to [16]

results are generated, e.g. in the form of product-ideas, product-functions, sketches or instructions.

The problem-layer describes the holistic and strategic view onto the topics sustainability and product development within a company. Here, the goal is to improve the understanding of the problem and the system in order to enable successful development.

On the goal-layer, the sustainability goals of the regarded product are defined. Modelling the goals enhances the developer's understanding of the problem, gives a certain direction to the search for solutions and allows to rate the solutions as well as the project-success.

On the path from the idea to the final product, the action-layer contains all activities that are required to fulfil the previously defined goals. Development takes place on the action-layer after having identified all negative influences of a product and having defined the respective sustainability-goals on the goal-layer [16]."

Indicator set according to [18]

Hertin et al. [18] developed a conceptual framework for considering the integration of sustainable development in enterprise policy. They elaborated a set of integration indicators for assessing products on enterprise policy level and added recommendations on how these indicators could be implemented. The aim of the study was to identify indicators that can support the formulation of an integration strategy and monitor the integration of environment and sustainable development into enterprise policy. The indicators originated existing initiatives in the area of sustainable development indicators and approaches taken by integration strategies in other EU policy sectors (transport, agriculture, …) [18].

Indictor set according to [17]
Issa et al. [17] presented a set of product-related environmental performance indicators (EPI) originating a systematic literature review, followed by a systematisation. They analysed the ambitions of manufacturing companies to identify, systematize and support the selection of product-related EPIs. The final result was a step-by-step guide to support companies in the selection of EPIs. In the framework of the review, 261 environmental performance indicators were identified and systematized in a digital database [17]. The database supports the application of the environmental performance indicators guide, which proposes a five-step approach to support the selection of indicators [17]. Issa et al. focussed on the environmental aspect of the indicators and structured them according to their relevant lifecycle phase (premanufacturing, manufacturing and design, …) and the addressed environmental aspect (material, energy, …).

Indicator set according to [19]
In contrast to the indicator set of Issa et al., which is focussing on the environmental aspect, the results of Hollauer et al. [19] comprise a list of sustainability impact categories and indicators, spanning all three pillars of sustainability. They represent a review of existing product-related sustainability indicators, which can be applied during product development for assessing of product sustainability [19]. They originate an analysis of existing frameworks and methods—standardized as well as others, which have been gathered into a single list. By conducting a broad review, all three sustainability dimensions have been included [19]. It has been found that a large number of diverse indicators exist for all three dimensions of sustainability, but the economic dimension is leading, followed by the ecological and social dimension [19].

4 Conclusion

Indicators are an established tool to evaluate strategies, products or actions in terms of sustainability but also controversial [20]. A recent example confirming this statement is the energy sector [21, 22]. In this context various technologies—especially renewable energies—are assessed by means of indicators and their contribution towards clean energy and a sustainable development is estimated. However, this procedure allows great clearances in regard to the selection, grouping and weighting of indicators, which is why a number of different evaluation frameworks and—as a consequence of this—different results exist. Nevertheless, the methodology represents a pragmatic means for operationalizing sustainability for different applications.

5 Assessing Sustainability—The Sustainability Diamond

Based on the fact, that sustainability refers to different dimensions the concretization of sustainability is characterized not of one but of multiple objectives. For the structuring of such complex processes, the decision theory provides several methods i.e. multi-criteria-decisions [23]. In the following only the two aspects of the operationalization and the identification of criteria and indicators will be descripted. Both, the criteria and the indicators are necessary in order to assess the sustainability of products.

The evaluation of products in terms of their sustainability is based on hierarchical operationalization of the guiding principle. From the dimensions of sustainability criteria are derived, which then indicators can be assigned as quantifiable values (see Fig. 2). According to the 'three-pillar model' the dimensions comprise the fields/sectors ecology, economy and social, which in the literature [7] are

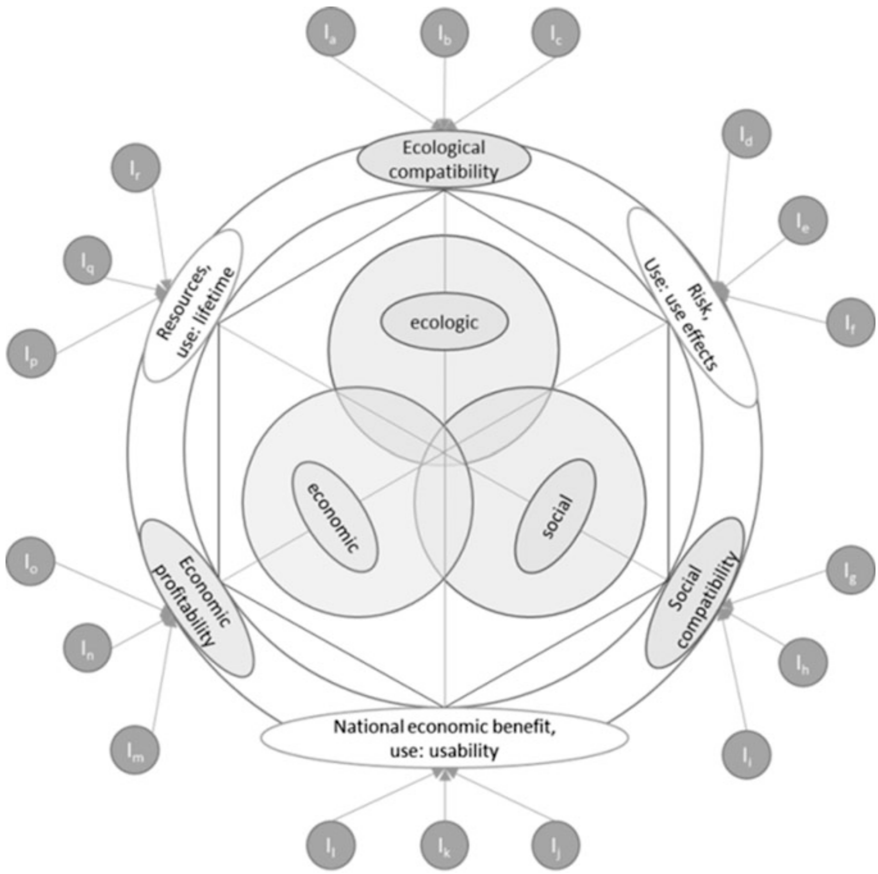

Fig. 2 Concept of the sustainability diamond

recognized as essential components of sustainability. However, these three dimensions are not enough for a differentiated assessment of sustainability of products. Therefore the dimensions will be extended at the level of criteria.

Related to the application assessment of sustainability of products in each case at the intersection of two dimensions another criterion is introduced. Result is a six-membered scheme with the criteria (I) ecological compatibility, (II) risk and use effects, (III) social compatibility, (IV) national economic benefit and usability, (V) economic profitability and (VI) resources and lifetime. The concept of the sustainability diamond intends to open the level of criteria for a weighting by actors, i.e. product engineer, product designer or manager. For this, the criteria have to be further concretized into specific requirements or guidelines, which define what a sustainable product needs to satisfy (according to [8]):

– Ecological compatibility: Product-related emissions and waste must not exceed the adaptation capacity and regenerative capacity of natural systems.
– Risk and use effects: Occurring hazards and risks to the product have to minimized or limited in their spatial and temporal extent.
– Social compatibility: Negative effects on user and producer have to be kept down.
– National economy benefit and use quality: The use quality of the product must be given.
– Economic profitability: The product must provide an economic incentive for the producer
– Resources and lifetime: The possible use of material resources must be kept for future generations or comparable alternative delivery models need to be created

The evaluation will finally take place at the level of indicators which allow the quantification of the criteria. In literature there are numerous sets of indicators regarding product assessment and focusing on sustainability. Based on this pool of indicators it is then time to make a targeted selection and assign the indicators to the previously determined criteria. While this selection process subjects the risk of subjective influence, the concept of the sustainability diamond operates an intensive literature review and evaluation to identify important indicators.

6 Application

The evaluation of products in the framework of the sustainability diamond is based on a two-step calculation. First, the indicators of a criterion are standardized (for example, from 0 to 1) in order to ensure comparability of the indicators. This is followed by an additive or multiplicative aggregation of the normalized indicator values within a criterion

In the second step, the values of the criteria are normalized and once more aggregated additive or multiplicative. In this context, a weighting of the criteria is provided. Thus, e.g. development engineers, sales managers, … are able to weight the criteria against each other and thus integrate their focus in the assessment. At the same time the results are graphically visualized in the sustainability diamond by plotting the index value of a criterion on the respective axis. Each of the six axes has a scale from 0 to 1 (normalized values of criteria), where 0 is placed in the center of the diamond and represents the lowest sustainability score. In contrast, a normalized criteria value of 1 represents the best score in terms of sustainability. Hence, the overall rating is determined by the size of the area of the resulting polygon. The weighting is represented by a corresponding marker on the respective axes.

7 Conclusion

Motivated by the presently high importance of sustainability on the one hand and the gap in the application of the guiding principle in the daily behaviour of people, policy decisions and also economic activities on the other hand, the paper presents a new assessment methodology to measure sustainability for product development. Embedded in a 3-level model of product development a measurement hierarchy starting with dimensions followed by criteria and indicators is introduced. Finally, the sustainability diamond consists of three dimensions, six criteria at the intersection of sustainability and use and a variable number of indicators. Furthermore the concept provides opportunities to integrate people and actors (stakeholder) as well as a dynamic aspect, which gives the user the ability to apply the concept to different topics. Both aspects are important especially for the consumer industry because of many companies consider sustainable economic activities as an investment in the own future ability and as an opening up new business opportunities.

In the current state the sustainability diamond is a concept for structuring sustainability indicators originating several sources from literature. In future research a support for selecting the important indicators as well as a process for weighting these indicators will be on the agenda. A very important aspect is the evaluation of the concept by practical application. So, evaluation within a student's project or industry is pursued.

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Understanding the Hope Harbingers—ASHA, the Women Foot Soldiers of India's National Rural Health Mission

Needa Jamil, A.S. Vysak, Aditya Parihar and Sharmistha Banerjee

Abstract This paper brings forth the case of a section of the Community Health Workers of India, called as the Accredited Social Health Activist (ASHA). ASHAs are young, school-educated rural women trained to promote health in their community. They are the grassroots level health care delivery mechanism for the Government of India's National Rural Health Mission. This study was conducted in Kumrup District, Guwahati, India. The aim of the study was to understand the impact of the program and the ASHAs on public health distribution in the district, their motivations, expectations, road blocks and hurdles. Also the study aimed at understanding the general satisfaction level of an ASHA due to the above mentioned aspects peculiar to the district and its impact on her performance of assigned duties. The paper concludes with possible design directions which can enhance the impact of the program by improving the satisfaction level of the ASHAs.

Keywords Public health distribution at bottom of pyramid · ASHA workers · National rural health mission

1 Introduction

An efficient and well-implemented healthcare system forms the backbone of a healthy country. However, in India, development process in health-care sector has been unsatisfactory on many accounts. It has been lagging behind other developing

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countries like China, Sri Lanka and Bangladesh in various parameters like healthcare infrastructure, life expectancy at birth, infant mortality, etc. [1, 2]. To strengthen the rural healthcare infrastructure and network, the Government of India launched the National Rural Health Mission (NRHM) in 2005. It aims to provide comprehensive and integrated health care to rural people, with a focus on women and children.

The Accredited Social Health Activist (ASHA) is part of the NRHM strategy. ASHA is a CHW appointed for every village with a population of 1000. She belongs to the community itself. The concept of using community members to provide basic health services to their own community is a pretty well established concept in India [3]. It's also a well-established and recommended practice globally as can be seen from the recommendations of the 1978 World Health Assembly in Alma Ata. They facilitate access to and utilization of health services, and inculcate healthy practices amongst communities [2, 4].

This paper presents a case study of the (GOI) Government of India's CHW programme, ASHA, and explores its strengths and limitations in the Kamrup district of Assam. ASHA was instituted by the Ministry of Health and Family Welfare (MoHFW) as part of NRHM in 2005. This has improved the utilization of healthcare services at the ground level in the country [5, 6]. The ASHA workers were mainly targeted to increase health awareness amongst women at the grassroots of India, the villages.

The motive for conducting this study was to evaluate the system; knowledge and practices; and, satisfaction level and its impact on performance of ASHA workers in the context of healthcare services at the base of the pyramid in the state of Assam in India. Also, this study explored the possibilities of implementing similar distribution system for other health schemes introduced by the government of India for underprivileged people.

2 Background

ASHA in Hindi means 'hope'. True to its meaning, it has played a pivotal role in the very design and execution of NRHM. It has been a critical mechanism in the GOI's promise on inclusive growth. Evaluating performance, knowledge, attitude and practices and satisfaction level of ASHAs is, therefore, crucial for the success of NRHM and hence of the inclusive growth strategy of the GOI.As per the current directives, following criteria are followed for executing and mobilizing the ASHA mechanism [7, 8]:

- Selection criteria—Resides in that village; Education—at least 8th class; Preferably 25–45 years of age; Selected by the Gram Sabha through community mobilization process.
- Preparation for the responsibility—Trained (23 days spread over a period of 12 months); Equipped with a manual and drugs kit; provided with periodic training, re-training and on-the-job training.

- Job responsibilities are—Acts as mobilizer, facilitator and a link between ANM [Auxiliary Nurse Midwife] at sub-center, Anganwadi[1] worker (under the Integrated Child Development Services program) and the community; Facilitates forging ownership of the community for the health program; Is the first point of contact for any health-related demands; Encourages women to register pregnancies and visit local health centers; Escorts people to the Primary Health Center (PHC) as per requirement; Brings children to immunization clinics; Encourages family planning (especially surgical sterilization); Treats basic illness and injury with first aid; Keeps demographic records and improves village sanitation; Holds information meetings and raise awareness on issues like women's health, disease, social determinants of health, nutrition and sanitation; Counsels on adolescent and female sexual and reproductive health.
- She is accountable to the Panchayat,[2] and will be entitled to receive performance-based compensation for providing following services—Health services for promoting universal immunization; Referral and escort services for Reproductive and Child Health (RCH) and other healthcare programs; Construction of household toilets.
- Her primary incentives include—INR 100 per day for immunizing children under the Pulse Polio Program; INR 600 for promoting institutional delivery; INR 900 for detecting malaria cases under the National Vector Borne Disease Control Program; INR 150/200 for Tubectomy/Vasectomy sterilization.

Figure 1 illustrates the support mechanism for ASHA.

3 Methodology

3.1 Demography of the Study

The study was conducted in North Guwahati, a block in the Kamrup district of Assam for 3 weeks. North Guwahati has a Block[3] Primary Health Centre (BPHC) which provides health services to the nearby towns and villages for a total population 1.2 Lakh. The PHC operates total of 109 ASHAs in the locality and 19 sub-centers with each sub-center catering, on an average, to a population of 5000.

In terms of facilities, villages under North Guwahati PHC vary greatly; some of them have adequate amenities like sanitation, electricity and primary schools but

[1]Anganwadi (meaning "courtyard shelter" in Hindi) is a government sponsored child (0–6 years) and mother-care center in India for Integrated Child Development Services program to combat child hunger and malnutrition.

[2]The Panchayat, in India, is a system of local government at the village level.

[3]Block is a district sub-division in India, which is next to Taluk level administration. For planning purpose district is divided into four levels: (1) Taluks, (2) Blocks, (3) Gram Panchayats, (4) Villages.

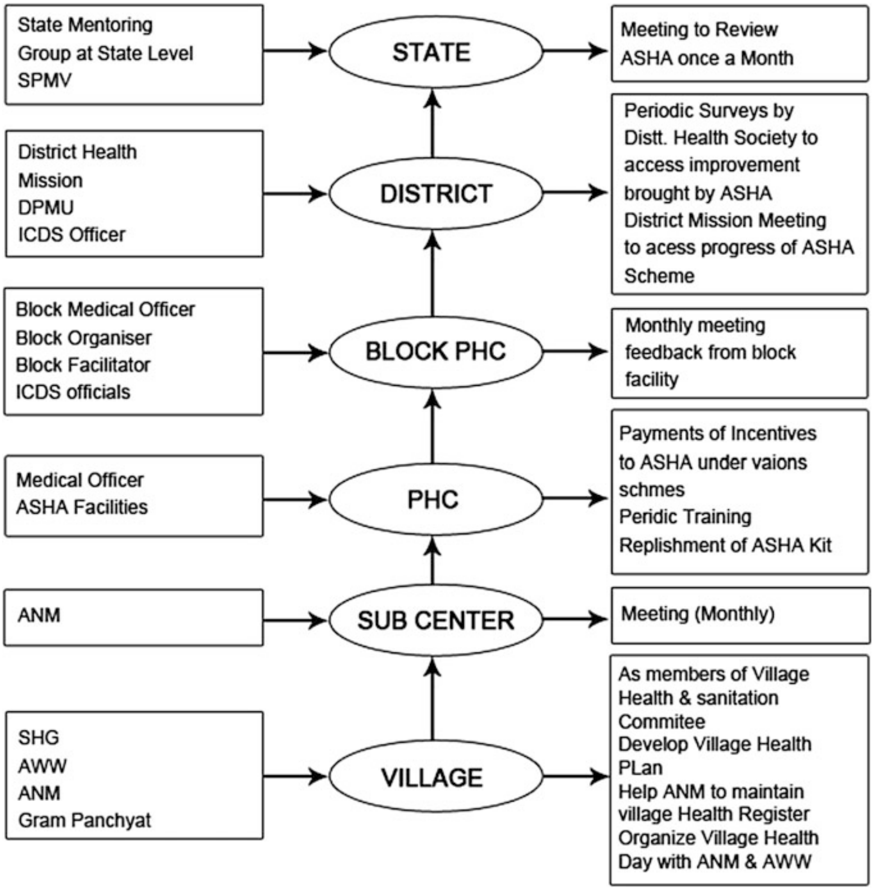

Fig. 1 Support mechanism for ASHA [9]

others lack even the basic facilities. Most of the men in this locality are involved in daily wage professions. Most of the women, in this locality, take care of household activities and children. Poverty is widespread in this area and has direct effects on access to basic facilities like health care. Unawareness about healthcare, sanitation, education and government schemes and policies for their betterment is very prominent. The block is a cluster of segregated communities formed based on different religious and regional backgrounds, tribes and professions. Because of the close proximity of all settlements, it is easier for the ASHAs to reach out to the people in her area. She also knows all the households personally.

Most of the ASHAs under North Guwahati BPHC are middle-aged married women in their fifties and have been a CHW since the program was launched by NRHM in Assam in 2006.

3.2 Data Collection

The data was collected through expert (supervisor and program manager) interviews, focus group discussion with people from the community, contextual enquiry and observation of PHC nurses and ASHAs. Three ASHAs were interviewed using a semi-structured questionnaire. The ASHAs were selected for the interview in such a way that they represent different demographics. This helped us to study the community effect (caused due to religious/regional background of the community) on their performance and satisfaction level. The first interview was with an ASHA belonging to the bodo[4] community, the second was with one who operates in Bihari[5] and Muslim dominant community and the third interview was with one operating in Bengali[6] dominant community. The subject matter expert (SME) interviews involved a supervisor and a program manager. Interview with the SMEs involved open-ended questions like "what changes have been brought through ASHA program in the public health distribution system?" and "what problems do ASHAs encounter in executing their duties?". This helped in gathering information about these stakeholders' thoughts and experiences related to community health issues and ASHA program. Conditions of the PHC and sub-centers were keenly observed during the contextual enquiry with the nurses and ASHAs. Focus group interviews with a group of local people in the community were conducted to understand social interactions occurring in the community, their perception about ASHA, her performance and their expectations from the program. All the data collected were mapped using affinity diagramming to figure out logical connections, gaps and opportunities to intervene.

4 Key Findings and Discussion

The primary vision of government, from the program, to improve the reach of health care services to the rural pockets of the country through CHWs like ASHA appears to seeing success. Institutional delivery rates have risen by 84% with child/newborn death going down 41% in year 2013 in Kamrup district [10]. Also, ASHAs have succeeded in making people aware about family planning and it has increased by 52% [11]. Contribution of ASHAs has a major role in the improvement of health services in the district. The Program Manager of North Guwahati PHC stated that 'ASHA has now become an integrated part of health care

[4]The Bodos are an ethnic and linguistic aboriginal group of the Brahmaputra valley in the northeast part of India. The Sixth Schedule of the Indian Constitution recognizes them as "plains tribe".

[5]Bihari are the people who originated from the Indian state of Bihar.

[6]Bengali are the people who originated from the Indian state of West Bengal and from the country of Bangladesh.

programs. They are now the basic health service providers at the grass root level and it is difficult to operate without their support". ASHAs and health workers mentioned that they enjoy interacting with their community and their work has uplifted their status in the community.

Despite the enthusiasm and positive outcomes, the interviews showed that there are still many problems with the program, which demand attention. These problems are around the ASHAs roles and duties, training, actual effective knowledge, income, time disposal, and supervision. Following are the key insights gathered from the study.

4.1 Motivating Factor—Social Status

In the study ASHA frequently cited the financial incentives as secondary motivating factor in continuing her work. One of the ASHAs stated that "*Delivery rates have reduced significantly now-a-days because of awareness about family planning, which is also one of her responsibility for which she has no monetary incentive. Hence, now monetary incentives are very irregular and not sufficient to rely as only source of income.*" ASHAs cited dignity and respect they receive from their community and interest in obtaining a government job as the major motivating factor. Thus they don't quit their jobs. But monetary incentives do play a major role in pushing ASHAs to carry out their responsibilities as they mentioned that they tend to ignore those roles that are unrewarded. One of the AHSAs interviewed proudly showed us the certificate she has received few years back as an honor.

4.2 Outcome-Based Payment Structure

On the monetary incentive account, the program is weak. For many ASHAs, their job is the only source of money. Hence, outcome based incentives like ASHAs can earn money only when she brings a pregnant woman to a PHC for requisite number of check-ups and institutional delivery happens, seemed breeding dissatisfaction amongst the ASHAs. The earnings for ASHAs in low population communities or communities with lower birth rate were not enough for sustenance. Also an ASHA has to conduct many activities like encouraging health meetings and discussing health issues but do not receive any incentive or reward for these. For example an ASHA reported that "*I get no money to go around all over the place and create awareness about health issues and engaging people into discussions. So I restrict my responsibility to deliveries and vaccinations for which I get paid.*" Thus, they do not perform many of the responsibilities that require time and efforts because of lack of proper monetary incentives. Because the incentives are outcome-based, income of ASHA through the program is very uncertain. ASHAs cannot rely on the program as the only source of income and have to engage in other activities for livelihood. Engagement in other activities leads to less dedication in terms of time and efforts as community worker. Also, payments to ASHAs are frequently delayed, mostly due to operational issues (e.g. funds not transferred, no clarity about available incentives, etc.). Also at times they were unaware of all the activities for which they could earn money while at other times, the documentation process was so tedious that they avoided even trying it. For example, they could earn INR 25 per injection that they administer to someone. But the paper work required in registering each such occurrence versus the money earned deterred them from applying for compensation.

4.3 Selection Process of ASHAs

The sub-center management committee selected the ASHAs. The criteria for selection are mentioned in Sect. 2. Most of the ASHAs in North Guwahati block are continuing since 2006, when they were first recruited. None of ASHAs interviewed had schooling till 8th standard and all of them were in their mid-fifties and above. While recruiting health conditions of ASHAs was not considered. It was observed that some of them have health problems, which restricts them to carry out all of their responsibilities. They are continuing because of the monetary incentives they receive which is an additional source of income for the family. One of them stated that "*Nowadays I am suffering from joint pains so it is difficult for me to take house to house surveys and conduct regular village health meetings. I don't want to quit because of the incentives I receive for deliveries.*" Also, if someone in the community is willing to take the responsibility, the older ASHA needs to give consent to quit her job. Some other observed drawbacks were as follows:

- For the old ASHAs with working son/daughter, the monetary incentive was not very attractive.
- These middle-aged women showed stronger faith in some unscientific and superstition based home-remedies and traditional practices, which can be detrimental to the health of pregnant women/new mothers/children.

4.4 Efficacy of Training

Though ASHAs need to undergo 15 days training when newly enrolled under the program, in the north Guwahati PHC only 9 days training was provided to the new ASHAs. They are also provided with the books that have basic medical guidelines (pictorially represented) but these books were rarely used by them. One of the ASHAs was a Bengali and did not know how to read Assamese, but all the books given to her were in Assamese. They also have monthly training sessions. Despite all the training provided, some of the ASHAs still continue to advice the prior-knowledge based methods of cure and remedies which can have harmful consequences. Also it was observed that being trained by male doctors was not a very comfortable way of learning for the ASHAs.

4.5 Clarity in Responsibilities

Other than child and maternal health care, ASHAs have been given other responsibilities such as construction of toilets for TSC, providing DOTS, provide care for minor ailments and etc. But they tend to take those roles for which they are monetarily rewarded and that too with less tedious paper work. Some of them are not aware of all the responsibilities that are reimbursable. Most of the ASHAs assume taking care of the mother and child health care as their primary and sole responsibility.

4.6 Medium of Collecting Data

ASHA workers record patient's details in a piece of paper, this piece of paper is passed through several offices (ASHA > Sub-center > PHC > and so on). Thus, the data can be lost before it reaches the district office.

4.7 Infrastructure of Health System

The structural hierarchy in the public health system creates hurdles in effective communication from the ASHA to the higher levels. Thus, ASHAs, even though have a better understanding of many issues in the community, are not able to transmit it to health professionals. For example, ASHAs have a good idea regarding what strategies motivate and de motivate women towards, say institutional delivery. These motivations are not merely limited to the INR 1400 that the mother makes by doing so. But unfortunately the knowledge regarding these motivations is not being tapped by the health care system.

5 Conclusion

From the stakeholder study, it is evident that ASHA as a program has very successfully tapped women across communities to come forth and serve their community towards achieving better health. Despite of the poor monetary compensation, the system has succeeded significantly in maternal and child health care segment. The psychological reward through enhanced social status of the ASHA worker has been the key driver behind this success. From our study, we recommend following design interventions, which can further build the capacity and capability of the ASHAs and also, bring forth higher success in other domains of health care distribution at the grassroots of the country.

Recommendations for administration of the program:

- Providing a fixed incentive monthly could improve the satisfaction level of the worker as this would ensure certain and continuous source of income. Though providing fixed monthly compensation should not eliminate the outcome-based incentive as it keeps the workers motivated to perform the task. Fixed monthly incentive could also help in making ASHAs feel more responsible about other activities like organizing surveys, group discussion and creating awareness and take as the part of their job which is currently absent.
- Providing performance based honor rewards in the form of some monetary as well as non-monetary incentives, certificates or prize money could motivate ASHAs to improve their performance and alleviate their social status further.
- The selection guidelines should be revised to select enthusiastic, young candidates with due consideration to physical fitness, family background, education, knowledge and willingness to learn scientific and medically proven/accepted health care practices.

Recommendations for possible Design Interventions which can enhance the program:

- Training modules can be redesigned. Few suggestions in this direction are as follows:
  - The first chapter of the training modules can focus on eliminating bias towards unscientific, traditional practices and cures.
  - Pictorial guidebooks can be replaced with a more engaging media involving radio, TV, posters or mobile phones. Further research in this area will be helpful.
  - At times when logistically it is not possible to hire educated women, separate training materials for them needs to be designed.
  - Female trainers can provide training so that the ASHAs can present their queries more freely.
  - Training to create knowledge of their job responsibilities and payment structure is required. Manual describing the same with breakdown of incentive versus responsibility will be helpful.
- ICT intervention at various levels, recruitment, training, job execution, payments, record creation and dissemination can be worked upon. This can on one hand ease the process, bring in better transparency and on the other hand further enhance ASHAs image in the society as a tech-savvy health care professional.
- A mechanism to tap the local knowledge, barriers and root-cause behind health issues of a region can be created through the ASHAs. This can be facilitated

when ASHAs can be also provided with a platform wherein they can share their experiences and grievances with the Health Care Management system.

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Supporting Sustainable Product Design: A Case Study with InDeaTe Tool and Template at Washington State University, Pullman, WA

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Abstract InDeaTe Tool and Template is a sustainable design support, aimed at imbibing and improving the sustainability considerations in any design. This paper presents a case-study on the 'design of a product' as a sustainable solution for the problems faced currently while making Wooden-fibre boards at the WSU on-campus facility, where an array of boards are made with wood-based materials, to the specifications of its various applications. The objective was to design a product in which the boards can be formed to completion—from laying, orienting to compressing in the hot press, without moving it from one station to another, ensuring care from damage and preferably with minimum human effort. The case study discussed in this paper, illustrates how the use of InDeaTe Tool improved the considerations of all dimensions of sustainability in a product and could be used for design of more sustainable products.

Keywords Eco-Design · Design for sustainability · Enabling technologies and tools · InDeaTe tool and template

1 Introduction

The Composite Materials and Engineering Centre, Washington State University, Pullman is an on-campus facility for designing, manufacturing and testing a number of wood based products, predominantly boards, to specifications as required for a

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number of applications and use. Currently these boards are made by hand, making the process tedious, labour-intensive, prone to damage while moving from one work station to another and most importantly exposes the people involved to industrial resins, that are toxic in nature, and dust from the wood-material. The resultant hand-made boards also have a lot of wastage from the sides where the board density is not even and needs to be cut. Another challenge is the thirty-minute window within which the entire process of laying the boards by hand to moving it into the hot press must be completed as the resin begins to lose its properties.

This case study illustrates the design of a product for easing the process of manufacturing wood-based boards, with improved sustainability considerations by using the InDeaTe Tool and Template. The resultant design is evaluated against the existing solution, to assess the improvement in sustainability considerations with the use of Tool.

2 Case Study: Overview

The goal is to assess the improvement in the sustainability consideration of the re-designed solution and in turn, the effectiveness of the InDeaTe Tool.

This is an exploratory Case Study and key questions studied are;

- Does the sustainability consideration improve with the use of the InDeaTe Tool and Template?
- How effective is the InDeaTe Tool and Template in supporting designer?

The underlying proposition of this case study is that the use of the InDeaTe Template and Tool improves the sustainability consideration of a product by supporting designers in formulating, iteratively improved List of Requirements with high sustainability-focus.

2.1 Problem Brief

OSB i.e., oriented-strand board, is made of flat strands of wood approximately half an inch in width and around four to six inches in length, oriented parallel to provide maximum strength. Another resultant product is the MDF (medium-density fibre) Board, which is made of fine fibres of wood clumped together like cotton. Few boards are made with a mix of materials while some are made in layers, later pressed into one. Certain boards are also designed into certain two or three-dimensional geometries for specific use or properties such as, increased compressive strength.

The existing process of manufacturing, by-hand, the wooden-fibre boards is as follows;

(i) different types of material; i.e., strands for OSB, chips and medium-density fibres for MDF; are resin-atomised in a blender
(ii) the now atomised material, upon volume measure for required board dimension, is spread by hand (also called “chicken-fed”) upon a forming box with a metal base plate
(iii) the material is chicken-fed on top of a suspended frame of vanes, adjustable in width, that help orient the strands; or rubbed on strings (banjo box) in case of MDF
(iv) once spread, the material is manually pressed to compact into a mat which is then moved to a scissor lift
(v) finally the mat is pushed into the hot press for the resultant board.

The **objectives** of this exercise is to design a product that eases human effort of making the wood-fibre boards, reduces damage to the mat, and perhaps even improves the board quality. The ‘chicken feeding’ process of laying as well as the basic input of atomized raw materials were given as part or constraints of the problem brief.

2.2 *Design Methodology*

The Design team followed the InDeaTe design process Template, where iterative GEMS (generate-evaluate-modify-select) activities of design are performed in each design stage while considering each life cycle phases of design.

This design exercise involved the first three design stages and followed the InDeate Template’s proposed design process steps to produce the following set of Deliverables, summarised in Table 1.

2.2.1 Exercise Duration

Approximately 35 h, Four Days

Day 1—Introduction of team members, Design problem and Site visit of the Composite Materials and Engineering Centre for Client interaction with Robert Duncan, Research Coordinator and IAS Quality Manager, and Prof. Vikram Yadama, Associate Professor and Extension specialist
Day 2—Design Exercise with Tool—Problem Definition and Task Clarification,
Day 3—Conceptual Design and Presentation of concept for discussions
Day 4—Embodiment Design, Design Analysis and Feedback on InDeaTe tool.

2.2.2 Participants

The Team Composed of Three PhD Students with Mechanical Engineering and Architecture Backgrounds.

Table 1 Case study: design methodology

Design stage		InDeaTe template: design process steps	Deliverables
Task clarification	1	Select system boundary	1. Preliminary List of requirements often qualitative with some understanding of their relative importance, often qualitative
	2	Analyse current situation to identify issues (generate requirement)	
	3	Using the tool/database select sustainability definitions and indicators to be used in the process	2. Some ideas of how to solve the design problem, noted down for further use
	4	Evaluate the issues to find the important ones to address (evaluate/modify requirements)	
	5	Decide on a list of requirements and their relative importance for use the subsequent stages (select requirement)	
Conceptual design	6	Generate alternative ideas to satisfy each major requirement (generate solution)	1. A more concrete list of requirements
	7	Evaluate these ideas to select the most promising ones (evaluate/modify solution)	2. A list of possible solution-variants that could be used to solve the problem (i.e. satisfy these requirements)
	8	Integrate these ideas to generate alternative solution principles (generate/modify solution)	3. An evaluation of these variants for their suitability to satisfy these requirements
	9	Evaluate these alternatives to select the most promising solution principle (evaluate/select solution)	4. The solution-principle selected as the most promising for further development
Embodiment design	10	Develop alternative, concrete configurations of the sub-systems/parts for the solution principle chosen in CD (generate solution): How can each subsystem/part of the solution principle be embodied? What are the other ways it can be embodied?	A more concrete list of requirements A list of possible solution feasible configurations that could be used to embody the solution principle

2.3 Analysis Methodology

For the analysis of the effectiveness of the InDeaTe Tool and Template, first the design solution conceptualised was assessed following which participants analysed the effectiveness of the Tool from their experience in the design exercise.

2.3.1 Assessment of Design with Respect to Benchmark

The final design selected as concept was assessed by Client for the following;

(i) The **Criteria** for the assessment of the design and in turn the Tool are;

   – Satisfaction of Requirement
   – Improvement of Sustainability consideration

(ii) **Data for analysis:** The resulting design is analysed with respect to the existing design, as benchmark, and data is in the form of List of Requirements, design sketches, design specifications and other documents.

(iii) **Units of analysis**: Qualitative analysis was performed by subject-matter experts to assess two aspects of the design;

   – *High, medium, low, zero* satisfaction of requirements
   – *Significantly improved, improved, not improved* Sustainability consideration

2.3.2 Analysis of Effectiveness of Tool

A retrospective analysis of the effectiveness of the InDeaTe Tool and Template was conducted via a Questionnaire posed to the participants.

2.4 Limitations of the Study

– The design exercise is conducted with one team performing a single-instance of design with use of InDeaTe Tool and Template. However, multiple case studies have been performed across domains to assess the same and the analysis results were found positive and corroborative.
– Due to the dearth of a parallel exercise as control, the original design has been used as benchmark to asses the sustainability improvement of the new design. And though it may be argued that there is always scope for improvement upon an existing design, the improvement proves that the Tool can be used to re-design existing issues effectively.

2.5 Key Findings of the Study

– The InDeaTe Template and Tool is effective for improving sustainability considerations in designs.
– The InDeaTe Template and Tool is effective in supporting the designer during the design process.

3 Literature Review

3.1 Relevance and Need for a Holistic Support

Literature presents a number of sustainability focussed design support are available but most of them are for assessment and evaluation; such as the Swiss Ecoscarcity methods (Ecopoints). While certain tools such as DFE Workbench though well integrated with Solidworks CAD tools, is able to support designers only with respect to the specific, in this case environmental, aspects of a design. There are also design methods that are developed that support only a specific Life Cycle Phase such as the Use-phase [7].

Literature also notes the existing "interaction of methods and tools at various steps in the process" of design and further stresses on the need for interaction between design methods and computer-aided tools to support decision-making [8]. Lopez-Mesa [9] enumerated potent findings about the knowledge and use of design methods in practice and highlighted that only a few methods are 'widely and systematically used' while most are unaware of the availability of other methods and believe that abundance of time is required. However, she notes that implementation of methods provides support to an array of tasks during the design process and leads to consideration of a large number of ideas. Lopez-Mesa further stresses on the increased positive contribution by a method upon the design when it is in a computer based system [9].

Thus, there is need of a computer-based support that encompasses all three dimensions of sustainability—society, economy and environment—across the entirety of the Life cycle of the design and addresses the need for improving sustainability of existing systems, with the systematic integration of methods and tools used prolifically in practice.

3.2 InDeaTe Tool and Template: A Novel, Holistic Design Support

InDeaTe Template and Tool, is a knowledge-driven Sustainable Design process support, aimed at imbibing and improving the sustainability considerations in a design. It comprises of two elements—a sustainable design process Template, and a sustainable Design Database—that work synergistically to support the designer on a user-friendly, computer interface. The Template and the Design Database ontology is based on the ACLODS holistic framework [1] which proposes dimensions—Activities, Criteria, Life cycle phase, Outcome, Design Stage and Structure—essential for life cycle development of a design.

The InDeaTe design process Template offers an overview of the design process and provides a generic guideline to follow as the design process is carried out. There

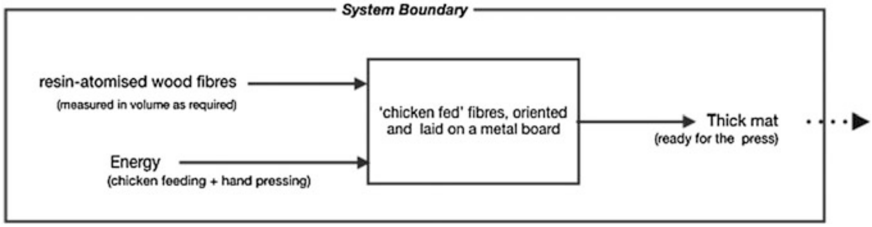

Fig. 1 Representation of system boundary

are four stages of design—Task Clarification, Conceptual Design, Embodiment Design and Detail Design [2]. And every design has five Life cycle phase, which are; Material, Production, Distribution and Transportation, Use and After Use. The Template encourages designing for the entire lifecycle of the system, with the aim of making it more sustainable. It guides the designer to perform suitable Activities of design, i.e., generate-evaluate-modify-select (GEMS) in each Design stage, at the intersection of every Life Cycle Phase. This is represented in the Fig. 1.

The Design Database is a comprehensive knowledge-base. It consists of a sub-database of Sustainability Definitions and Indicators, that help clarify the design task at hand with respect to the sustainability perspective while the corresponding sustainability Indicators prompt the suitable sustainability considerations in the design. This is further linked to a sub-database of Design Methods and Tools, that aids the designer in the design process to achieve those sustainability considerations.

4 Design Exercise

The team used the InDeaTe Tool and Template to perform the exercise. The designers began to navigate through the Tool upon selecting 'Product' category for type of design, as was made explicit by the clients.

4.1 Task Clarification Stage

In this stage, the design team well defined the problem statement with the intent to identify a preliminary list of requirements.

Step 1: The design team followed the Template and **Selected a System Boundary**, as represented in Fig. 1. Upon client interaction it was clarified that the resin material, blenders and the resin-atomising technique were clearly out of the design scope. The product-system boundary was identified to be from the point of resin-atomised material being available for forming till the point of the material-mat being in the hot press.

Step 2: The design team **identified other constraints**; (i) maximum time to form the mat and move it to press (30 min) and (ii) the maximum dimension of a mat (*8′ × 4′, variable height allowed*), were definite constraints.

However there were many **scopes of intervention** that were noted, such as;

- the manner of transferring the resin-atomised material from blender room,
- the manner of dispensing the resin-atomised material, (*noted: chicken-feeding is highly effective*)
- the manner of orienting the material, (*noted: the vanes are effective but edges are brittle*)
- the manner of moving the ready mat, (*noted: lifting the mat causes damages*)
- the in-use equipment such as vanes and forming boxes.

Next, the design team **analysed the current situation to identify issues** and generated (G) requirements

The existing system could be decomposed into the following tasks—the orienting and laying of resin-atomised material, compressing the material into a mat by hand, and moving of the mat onto the scissor-lift to be rolled into the hot press.

And each of these tasks had certain lifecycle issues that required to be addressed, such as;

- The orienting and laying had a Manufacturing-phase issue where the quality of the product (mat) was not consistent. However it was clarified that the forming boxes and vanes for made of wood and metal, has long life of up to 20 years and can be re-used several times.
- The laying and compressing the material by hand had Use-phase issues, as the person involved gets exposed to the resin and dust, and causes posture-related issues.
- The moving of the mat onto the scissor-lift to be rolled into the hot press, again had a predominantly Use-phase issue with the persons involved being responsible for the timely and un-damaged mat being moved. And often this is contributed significantly to the waste generated as delayed or damaged mats cannot be re-done due to hardening of resin.

In order to well-define the problem, the designers **formulated a Solution Neutral Problem Statement (SNPS)—***To design a device that lays resinated wood chips/strands/fibres as a mat with uniform depth and orientation, adjustable for various sizes, within a time constraint, ready to be moved into a press, and operated with minimal human effort.*

Step 3: The design team then turned to the Tool and chose the **TBL scope—society and environment**, for this particular design and argued that in a Design and testing facility such as this, economics was not a critical concern. The Tool has a list of Sustainability Definitions—a repository of over 80 definitions and principles available on the tool's design database, from which the designers **selected Sustainability Definitions, Principles and Indicators** for their design process. The team found the World Bank [3] and the Sustainable Seattle [4] definitions to be appropriate, based on the aspects of TBL that each encompassed and in turn this was used for scoping and directing the motivations of the design via Indicators.

Upon selecting the definitions, the Tool further provided a **set of Sustainability Indicators** that would be used to operationalise the selected definitions. These were;

- Living condition (Social Indicator): Rates of injury, occupational disease, [5];
- Waste generation (Environmental Indicator): Generation of general waste, Generation of hazardous waste [6];

Th Template does not dictate consideration of constraints, including critical ones such as as cost and time, are left to the designers depending on their priorities and requirements.

Step 4: These Indicators persuaded the generation of requirements and the design team pragmatically conducted an **Evaluation of issues** to find the important ones to address. As a result, some Preliminary Requirements were generated (G) upon evaluation (E) and few modifications (M);

- eases human effort of making the wood-fibre boards (from laying, compressing to moving of mat into press)
- improve human working conditions
- reduce damage to the mat caused due to multiple instances of moving (from forming box to scissor lift to press), and
- improves the board quality (orientation of fibres and uniformity of depth)

Step 5: And to **prioritise these requirements**, the design team selected **Quality Function Deployment or QFD Method** and used the **'House of Quality' (HOQ) tool** that is based on it, illustrated in Fig. 2, from the Design Database.

As a result, the design team met the **Task Clarification Deliverable** of formulating a **Preliminary List of Requirements,** which was;

(i) Improve working condition—exposure and ergonomic
(ii) Precisely oriented wood chips/fibres
(iii) Consistent depth
(iv) Mat easily movable into Press
(v) Ease of use
(vi) Minimal Wastage: Maintain spreading time (limit of 30 min)
(vii) Minimal Wastage: Avoid brittle edges

4.2 Conceptual Design Stage

In this stage, the design team explored a number of solution-variants and worked towards selecting the solution-principle or "concept".

Step 6: The team **generated (G) alternative ideas** to satisfy each major requirement and to do so selected the **Brainstorming** Method from the Database.

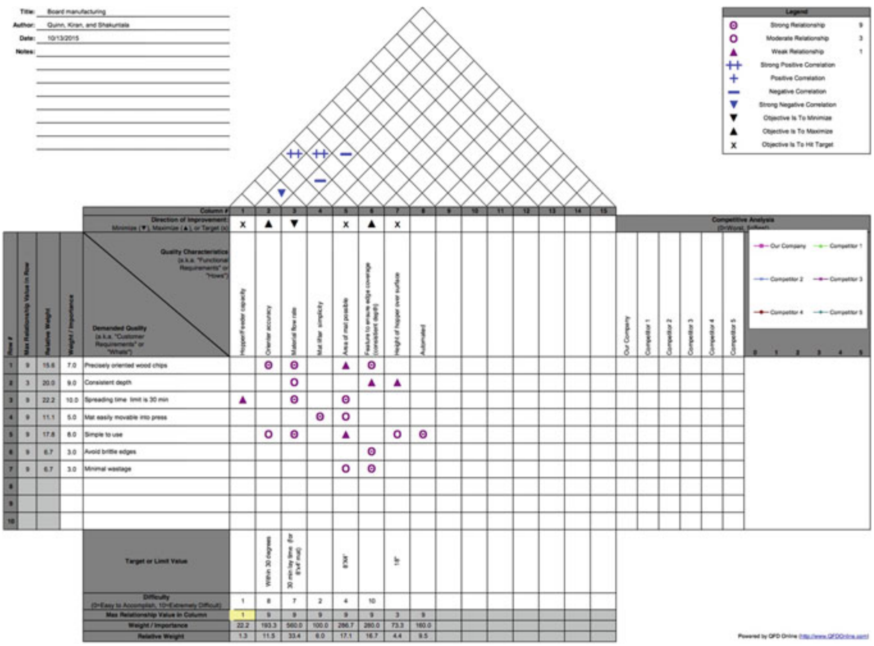

Fig. 2 House of quality for QFD

The result was a number of ideas for each of the requirements, decomposed as sub-functions, as given below;

– Sub Function 1.1: ALIGNMENT of Material (resinated)

  vanes v/s disc
  magnetic
  blow air through slot
  Funnel/s in parallel—line opening, oscillation
  single hopper (like a 3D printer) in X-Y axes
  accordion like walls to physically align [& vary in size]

– Sub Function 1.2: LAYING (chicken feeding)/Spreading

  oscillating base
  a shaking pourer on top of the aligning device

– Sub Function 2: PRE-PRESS to form mat

  rolling pin {issue: alignment skewed; may require shaping}
  panini press

– Sub Function 3: MOVE to Press

  Form inside the press
  Scissor-lift table → motorise the rollers
  Conveyor

Step 7 and 8: These ideas were then evaluated to see which were feasible and which ones would have greater effect. The design team used the **Morphological Chart** Tool, an example given below in Table 3, from the Database. It was further used to combine solutions and generate six solution-variants, namely Q#1, Q#2, K#1, K#2, S#1, S#2, two by each designer with the initials of their names, an example is given below. These variants were sketched as part of the generation/modification of solutions.

Step 9: The design team next, evaluated these alternatives with respect to **LCA (Life Cycle Assessment)** and **MFA (Material Flow Analysis)** Methods, by assessing the sustainability of the solutions based on the following parameters;

– LCA: Use materials with lower environmental impacts, lower energy consumption and with higher recyclability
– MFA: Use materials with higher strengths & longer life to reduce material needs, and use pre-existing parts where possible

From the solution-variants, the solution-principle was eventually selected by the team by using the **Lexicographic Decision rule** from Methods Database, in which the product attributes, developed from the previous list of requirements, were ranked based on their importance and compared. As a result, the design team agreed upon the section of the solution-principle or 'concept' to be embodied.

Thus, the design team fulfilled the **Conceptual Design stage Deliverable** and the concept specifications for the given design problem, illustrated in Fig. 3, is as given below;

- **Single line opening wide-mouth funnel** into which the resin-atomised material is supplied through a tube from the blender room,
- **Oscillating double sieve-plates hopper** lay and align material to form mat,
- Mat is formed on on a table-height **Conveyor**; that moves back and forth as required for desired thickness of mat,
- **Existing forming boxes,** of specified dimension as required, are re-used fitted **with inward slanting walls**, allow thicker material deposit at the edges, and
- **Rolling-pin** along the width of the conveyor, on the other side of the hopper, compresses the mat after removing the forming box, prior to moving into Press.

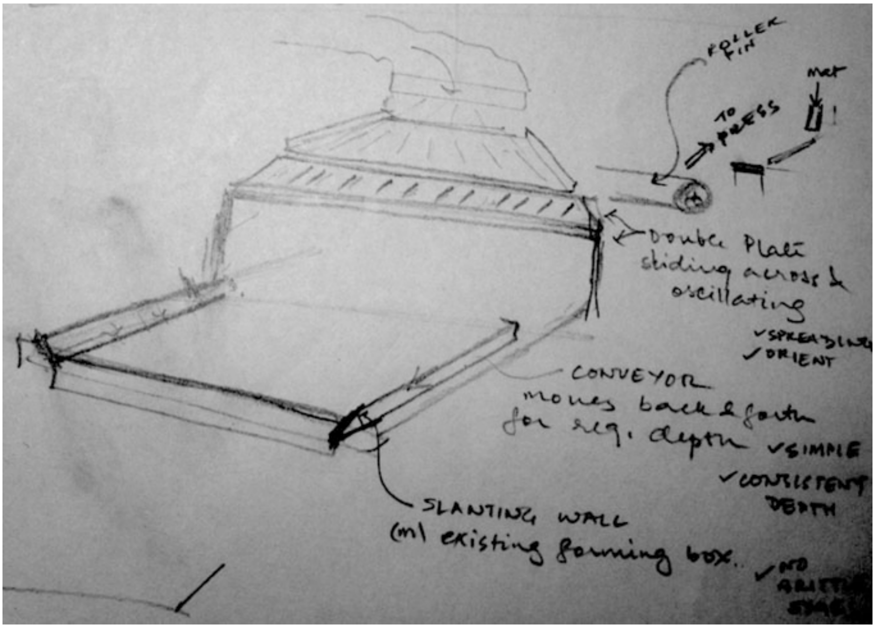

Fig. 3 Sketch of selected concept

4.3 Embodiment Design Stage

In this stage, feasible configurations were developed for the selected solution-principle.

Step 10: a number of In order to assess the overall success of the solution-principle as a Product, a **Failure Tree Analysis** as in Fig. 4, from Methods Database was performed by the design team and a refined List of requirements was delivered.

The **Deliverable** of a **Refined List of Requirements** is as follows;

- Conveyor Belt—Rubber or Cloth
- Hopper—aluminium or steel
- Rolling Pin—Steel, hollow pipe
- Internal Material distribution vanes—aluminium

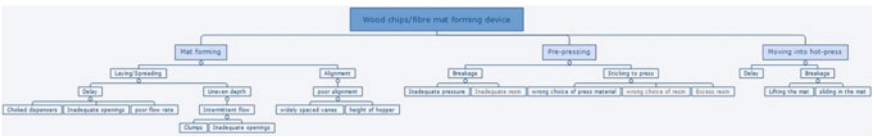

Fig. 4 Failure tree analysis

- Conveyor motor and Oscillating motor for hopper *(*operational energy to be considered)*
- Structural Frame—Metal and wood
- Pre-existing for re-use;
- Scissor lift
- Material laying plate
- Wooden forming boxes
- Material feeding tube—rubber lined tube *(*resin properties to be considered).*

5 Key Findings

5.1 Design Assessment

A number of design solution-variants were presented to client to assess the final concept design with respect to the benchmark for requirement satisfaction and improvement of sustainability consideration of the Service system designed. This is presented in Table 2.

The clients' assessment was based on benchmarking the proposed

product design with respect to the existing manufacturing system, and noting the improvements if any. The assessment was conducted based on two criteria; requirement satisfaction—to assess the overall quality of the concept selected to become a "good" and successful product, and sustainability consideration to note the degree of improvement.

The most significant contribution of the InDeaTe tool and template to the design was the formulation of succinct requirements with sustainability as key for consideration, which not only determines product success, but also the overall impact of the product. The InDeaTe tool and template systematic helped identify and refine the requirements to be addressed—such as, working conditions—and in turn, improved the design process with sound guidance of design methods applicable as per stage and activity of design.

The results of the two criteria were in consensus which may be viewed as a validation of the InDeaTe Tool and Template as an effective support to improve sustainability of a service system.

5.2 Analysis of Tool

The results of the Questionnaire were overall positive with designers stating that they found the Tool useful

Table 2 Assessment of design—proposed solution benchmarked to existing solution

Requirements	Existing solution	Proposed product solution-principle	Requirement satisfaction	Sustainability consideration
Improve working conditions—ergonomics and exposure to hazard	– people bend over to work, – ‘chicken feed’ the material by hand	– table height Conveyor, – automated product	High	Improved significantly
Precisely oriented wood chips/fibres	– suspended vanes	– Oscillating double sieve-plates hopper	Medium	same
Consistent depth	– material laying and required depth done by hand, increase in exposure	– Conveyor moves back and forth as required for desired thickness of mat	Medium	Improved significantly
Mat easily movable into Press	– mat would be moved by the persons involved	– Mat is formed on a Conveyor; – Rolling-pin along the width of the conveyor to compresses the mat prior to moving into Press	High	Improved significantly
Ease of use	– the resin-atomised material is carried in buckets	– automated – the resin-atomised material is supplied through a tube from the blender room	High	Improved significantly
Minimal wastage: maintain spreading time (limit of 30 min)		– automated system that not only maintains time but efficiently manages it	Medium	Improved
Minimal wastage: avoid brittle edges		– Existing forming boxes (of specified dimension) are fit with inward slanting walls to allow thicker material deposit at the edges	High	Improved
			Satisfied	**Sustainability improved**

Table 3 Morphological chart tool

Design parameters	Solution—variants (S#1)					
Laying	Vibrating full width hopper	Oscillating base	Hopper moving x-y	Set of parallel hoppers	Single adjustable width funnel	
Alignment	Magnetic	Air flow	Line opened funnel	Accordion	Vanes	Rotating discs
Pre-press	Rolling pin	Flat plate pressed	Panini press	No pre-press		
Move	Form inside press	Form on scissor lift	Conveyor	Form outside and move in with scissor lift/manually		

InDeaTe effectively supported the design team to;

- identify key areas of improvement from the Sustainability Indicators, which behaved as prompts
- integrate various considerations with use of methods
- evaluate and select a "good" concept which satisfies the requirements and achieves improved sustainability considerations

6 Conclusions

It was a successful design exercise as the proposed design outcome was a Product with higher sustainability considerations and satisfied all the requirements of the clients without compromising on the quality of the boards. InDeaTe Tool and Template supports designers to improve sustainability of a product and is recommended for design of more sustainable products.

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Design's Role in Transitioning to Futures of Cultures of Repair

Tristan Schultz

Abstract This paper traces a historical and conceptual terrain of cultures of repair from a decolonial and ontological design perspective, i.e., through decolonial design. In the face of present and mounting future challenges, particularly Climate Change, consequent migration and global unsettlement, indiscriminately reaching all geographies, cultures of repair afford ecological, social, and technological exemplars of adaptation and resilience. Yet neither the complexity of the trace nor the imperative for appropriation is adequately reaching designers. To explore filling this gap, a relational map is presented here, that aims to aide designers understand four key threads implicated in the destruction of cultures of repair—*concealment; newness; techne; care*—and three key moves toward revaluing cultures of repair—*transferrability, reclassification, amplification.*

Keywords Cultures of repair · Repair · Decolonial design · Recoding · Design · Modernity · Colonialism · Climate change · Resilience · Sustainable futures

1 Introduction

There is a new space opening up for discussion around the word 'repair' and its role in transitioning to sustainable futures. This space is raising important questions concerning the role that modernity and colonialism have played in both destroying and inculcating cultures of repair. Decolonial studies provides a useful framework for engaging with this trace. When coupled with critical design discourse, decolonial design praxis may effectively transfer and amplify resilience afforded by cultures of repair persevering amongst the maelstrom of modernity/coloniality; both gathering in the present and waiting for our arrival in future. In the present, it gathers in the margins; in cultures where everyday practices in care and repair persist in breaking the mold of a colonial matrix of power. As Stephan Jackson [1]

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writes of these places, many of the stories and orders of modernity are in process of coming apart, perhaps to be replaced by new and better stories and orders, but perhaps not. At the same time, the aftermath of modernity arrives at our feet, such as in the form of climate change. Amongst these tensions and in the face of future challenges indiscriminately reaching all geographies, neither the complexity of the trace nor the imperative of understanding sustainable, futuring, designed/ing affordances present in informal resourcefulness, resilience, bricolage and repair is adequately reaching designers, design engineers, product developers and policy makers more broadly. In order to assist closing this gap, this paper maps a terrain where one might begin. This study therefore contributes to advancements in design and design engineering in a similar vein to Devadula and Chakrabati in questioning the ontological designed/designing "entangled co-constitutive relationships which humans and technology are in" [2], as transitioning to human sustainment increasingly becomes a prescient concern.

Decolonial Design: The last 500 years have left all cultures, lifeworlds and the entire planet in all its 'worlds' entangled in power differential spaces between modernity/coloniality [3]. Research is emerging into the ontologically designing historical and futural consequences of this, particularly in ontological design with the agency of sustainable futures, most notably through Redirective Practice [4] and Transition Design [5]. Coupled with decolonial studies [3, 6] an emerging terrain of *decolonial design* is developing in plural contexts globally, one such suite of articulations can be seen through the recently released 'Decolonising Design' online platform authors [7, 8]. In general, decolonial design is disobedient to dominant Western design research in that it follows a political objective of three streams: (a) *unlearning:* critical unravelling and exposing of Eurocentrism, (b) *learning:* directing thinking-in-action toward identifying what can be learnt from different modes of being-in-the-world, (c) *praxis:* redirecting away from the hubris of European modernity towards amplifying pluriversal worlds, while not ignoring inescapable entanglements amongst modernity/coloniality [3]. Contrary to a grand totalising vision, working on local situated concerns would be the measure of decolonial design. In this way it aligns with a commitment to 'cosmopolitan localism' [3, 6, 9, 10]. That is, as Cameron Tonkinwise [5] suggests following Ezio Manzini, "geographies must be designed to be hospitable to foreigners and not just to those fit for the local ecologies. While withdrawing the meta-narrative of global progress, they nevertheless must each in their own way, perpetuate the project of diversification in order to be open to divergent diversity and migratory difference". And finally, decolonial design is an ally with how Arturo Escobar [11] outlines, "a research and action project for advancing an ontological design approach to the pluriverse, or 'a world where many worlds fit'".

Cultures of repair: At any given time anywhere in the world, two remarkably disparate repair cultures exist. The first are entrepreneurial maker cultures, somewhere between naively and blatantly bound up in what Filipe Fonseca [12] argues are capitalist vocabulary's stemming from the Industrial Age. These repair cultures have been seduced by industrial economies and productivist imaginations, making prototypes, usually of plastic that end up in waste, striving towards industrial standards and mass production. This mode has the backing of governments worldwide, e.g. President Barack Obama's [13] manufacturing innovation hubs and Prime Minister Malcolm Turnball's innovation nation [14] (Australia) are seduced by 'maker cultures' potential as the engine of a third industrial revolution.

The second are innovative repair cultures constituted by billions of people across the globe making do with what is at hand, through necessity, voluntarily reducing wastefulness or practicing ethics of care and cognitive satisfaction in repairing things; untied or contesting the formers productivist models. The former appropriate and reclassify the latter's political position for their own capitalist means. As Fonseca [11] suggests in his discussion of *Gambiarra*, the Brazilian culture of repair, there is a world of difference between an attitude of hacking to repurpose and a techno-evangelism that makes without any thought for what it destroys. Similarly to *Gambiarra*, French anthropologist Claude Levi-Strauss [15] defines the *bricoleur* as being adept at performing a large number of diverse tasks, but he says, unlike the engineer, his rules of engagement are to make do with whatever is at hand. In India, *Indovation*, or *Jugaad*, has become "representative of the Gandhian ethic of localized empowerment [16]. However, Thomas Birtchnell notes a caution that corporatized co-optation of local practices to entice Indians to consume is also occurring. In Japan, the *Wabisabi* worldview deriving from Buddhism instills a kind of sacred design mentality, of transience and imperfection, practiced in one's relationship to things, most notably though *kintsugi,* or 'golden repair' of ceramics [17]. Other examples such as from the American Great Depression [18], to Cold War Russia [19] to more recently, Papua New Guinea [20], illustrate how famine, conflict and oppressive regimes have ontologically designed conditions of cultures of repair.

In the maelstrom between these two disparate repair cultures, open source digital culture movement, fablabs, hacklabs, repair cafes, maker faires, DIY and craft communities exist. Furthermore, contemporary movements such as 'slow design' [21] and the steampunk movement [22] share commonalities with repair cultures; of breaking, re-shaping, tinkering, DIY and craft. The argument made here is that regardless of which mode, cultures of repair performative directionality sits in the borders between the residue and gathering; the seduction and repression, of modernity/coloniality. These relationally connected traces need to become part of a designer's vocabulary, beyond the current more simplistic narrative of cultures of repair, along the lines of 'the world has a limited amount of resources to use, so we need things to last longer before we have to use anymore resources so we might repair things instead of throwing them out'.

2 Method

This paper seeks to locate a way to speak of repair in a decolonial context and for this to become decolonial design praxis. Therefore, a critical analysis focussed on enquiry into the ontological nature of the relationship between humans and things, with texts chosen from hermeneutic phenomenological philosophy, critical cultural theory, decolonial studies, critical design and technology studies. The texts were interrogated through central questions: (1) What is being said about repair and its role in transitioning to sustainable futures, particularly what role has modernity and colonialism played in both destroying and inculcating cultures of repair? (2) In the face of Climate Change and global unsettlement what kind of praxis is emerging in amplifying decolonial design afforded by cultures of repair? (3) Are there visualisations assisting designers to this end?

3 Results

The analysis identified four key threads being spoken about in relation to the first and second research questions, therefore these are brought together in a cohesive order and discussed below as *concealment; newness; techne; and care.* In relation to the third research question there presents a gap in knowledge for a visualisation, to read in conjunction with these threads, therefore the 'Cultures of Repair Relational Map' (Fig. 1) has been designed. The aim of the map is to assist designers comprehension of the gathering of modernity/coloniality and its arrival in futures (Fig. 1. part A) in order to be in a position to amplify sustainable activities in repair cultures through decolonial design (Fig. 1. part B).

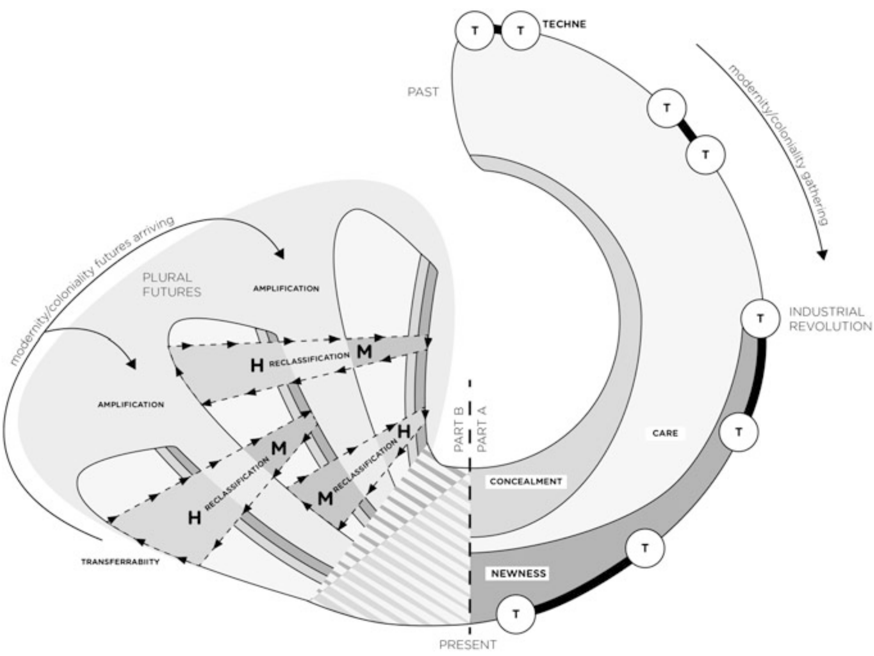

Fig. 1 Cultures of repair relational map (*Source* Tristan Schultz)

4 Discussion

4.1 Key Threads (Fig. 1, Part A)

Concealment: The phenomenon of concealment has grown incrementally over thousands of years, and best appears in the present in the term 'out of sight out of mind'. The secret lives of objects are concealed in globalized distribution processes and glossy designed packages. Tracing back to agrarian societies, objects were seldom technologically advanced enough to conceal components. Up until the Industrial Age, the level of advanced technological capacity to conceal things was minimal, component parts were seldom out of sight, hence not out of mind. To the contrary, parts were seen, honoured, understood and respected for their inherent craftsmanship. Due to the Enlightenments productivist imaginations fuelling the first Industrial Revolution accelerated technologies developed enough for objects to become much more complex, efficient, smaller with component parts concealed and hence unconsidered. As a surplus of objects accumulated from an acceleration of mass production, advertisers and designers of commodity culture began concealing parts for reasons beyond technological means. The *image* of the *modern*—clean surfaces made desirable—meant consumers no longer cared for hidden parts, nor could they identify which parts might be in need of repair, laying the conditions for systematic planned obsolescence and built in redundancy, decreasing the desire to repair and increasing the desire to consume. That we are emotionally detached through this concealment adds to ontologically enforce our techno-evangelist support for more technical things to suit our fast paced consumer driven lives.

Newness: The culture of newness has grown rapidly with the rise of consumerism since mid 20th century, directed by the Wests imperialist development parameters. Traditional and/or non-western images were recoded as not as advanced, civilised or wealthy as the seductive image of the modern and, subsequently, not as desirable. Modernist designers designed a modern aesthetic style with the symbolic significance of the status of wealth [23]. Increasingly what propels design is the speed of change of styles, a spectacle inherently needed for the perpetuation of the market in a capitalist economic system [24]. This means that newness works against the time things may have as operative existence [25]. Propounding this is a concealment of parts, meaning the life of the thing is dependent on the shortest life of a single hidden component. If a culture is not prepared to balance the price of destruction with giving operative enduring time to the things it creates, then it is a culture of newness. If it offsets the operative enduring time of a thing with repair, it is contesting the spectacle of newness.

Techne: the techne' is explored here as the phenomenon of craftsmanship; of the craftsman engaging with conceiving a tool, tool-use and tool-repair respectively; as constituting being-human [2]. Over time, particularly as an intellectual thought since the Enlightenment, Martin Heidegger [26] argues, what he termed as the present-at-hand dominates our everyday experience in that we are only concerned with observing things when they lose their usefulness and fail to operate the way we expect. We look at the thing, disassociated from it, and observe its broken properties. To the contrary, when a tool or thing is useful it is ready-to-hand, appropriate for a task; not broken nor demanding our concern. Nigel Thrift [27] argues that it is in this space, between the visibly ‘broken’ and concealed ‘tool’ that “repair and maintenance makes its bid for significance”. The presence-at-hand enables a visibility of the order of things, which we are concerned with getting back to a ready-to-handiness so the world can go on. This phenomenological approach suggests that breakdown and decay are central necessities to a life purpose [2]. With the human hand as tool bearer, the relationship between the presence-at-hand and the ready-to-hand forces a reflection on being human; repair reminds us we are human. To value remaining human, is to contest against the mechanization of man by working with the hand to curb a world rendered meaningless by the hands dissociation from reflective action. Concealment and newness, explored above, produce non-repairable things, which coupled with the discussion of the hand here, reinforces the designing out (ontologically) the associative meaning we make with our everyday experiences in the world through hand actions of bricolage, maintenance and repair.

Care: An ethics of care has diminished considerably as a consequence of modernity. Prior to this, dominantly across the globe, care for repair had been inextricable with life affirming cosmologies and ontologies inculcating reciprocal exchange with the biosphere upon which they depend. However, over the course of modernity/coloniality attention is redirected away from this bind. The Society of the Spectacle, Guy Debord [24] argues, now colonises our attention. Similarly, Bernard Steigler [28] writes, our attention is captured by “the psycho-technologies that have developed with the radio (1920), with television (1950), and with digital technologies (1990), spreading all over the planet through various forms of networks”, a vicious circle of the destruction of attention for anything or anyone beyond subjects of a spectacle. For Zygmunt Bauman [29], this lost proximity to the Other further manifests through the colonization of privacy, sensitivities and dignity, eroded through the proliferation of the likes of Facebook and other social media demands, as an insensitivity to human suffering; a moral blindness. A proliferation of concealed, new, consumer driven objects and things coupled with a disassociation from reflective action has brought-forth a deterioration of repair practices; a fissure where social technologies now further compound an erosion of attention and care for repair. Added to this is our short-term attention span, where we only have ‘time to care’ for very few things and not for a very many other efficient, convenient, durable, reliable, distant and imperceptible others in ‘no need of repair’.

4.2 Towards Decolonial Design (Fig. 1, Part B)

Some designers are moving to counterbalance all this with designs that require more laborious material interactions, built in regimes of maintenance and repair, disassembly and transparency. Some are following the path of Japanese *kintsugi* by increasing the sign-value of wear and tear, such as Emotional Design [30], which insists on deep and meaningful relations between humans and 'evocative objects'. An issue with some of these movements however, is that many cultures are still dealing with the leftovers of the modern world piling at their feet. Moreover, as the world increasingly accumulates waste, migrates and generally feels the affects of global unsettlement, so too will these piles indiscriminately permeate previously sanctioned geographies and city streets. Therefore, as has been drawn together above, searching for sustainable futures might focus on a more poignant framing of the trace of the decay that already exists and the ways cultures are creatively innovating with this decay.

There is an argument that designers can put to task their skills, techniques, and mentalities to designing decolonial futures aimed at, as Escobar asserts, advancing ecological, social, and technological conditions where multiple worlds and knowledges, involving humans and non-humans, can flourish in mutually enhancing ways [11]. He contends that communications strategies in this vein would serve two main purposes: "to construct narratives that persuade people to think about why the One-World story no longer quite makes sense; and to contribute to make visible the projects by which other practices attempt to persevere and perform themselves into worlds" [11]. The construction of the above four key threads begins serving the first purpose. A designer can then enfold the second of Escobar's call to action through three successive modes; *transferability, reclassification and amplification*.

Transferrability: As populations increasingly move, both the trace of barriers and the trace of perseverance move with them. As Michel Foucault would remind us, central authority fragments as one moves unshackled from centres of power. On top of this, as one moves, one carries less, enforcing objects and things to be multi-use and whatever is unready-to-hand becomes present. Conspicuous, obtrusive and obstinate things [26] enter perceptual experience and concern, and are bricolaged or repaired. This suggests a three-fold act occurring, of (a) moving with repair skills from their geography; (b) unshackling power through moving from their geography; and (c) elevating perceptual aptitude to exploring for new innovative bricolage and repair while on the move. These three knowledge acquisitions are not present in a host geography in stasis. At the same time, in any host geography there might already be present situated cultures of repair. They may be (a) a non-sedentary culture existing for many thousands of years, whose localised movements are bound with an ethics of care and repair; (b) frivolously persevering where modernity/coloniality has inculcated a culture of repair; and (c) coming to terms with the precarity of their stasis and in early stages of movement and flux bringing-forth new perceptual aptitudes to exploring innovative bricolage and repair. These three knowledge acquisitions may or may not be present in other geographies in stasis, nor in the cultures of those arriving. This illustrates six 'transfer gaps' in research in which a designer might focus their exploration.

Reclassification: As transfer gaps turn to praxis an inescapable reclassification of the symbolic value of any repair activity occurs; this has happened to repair before. Disruptive technologies, distributed manufacture and fablabs have been reclassifying the word 'repair' for their own productivist means for some time.

Remaining focused with an agency of decolonial design here, the question is what reclassification might create sustaining qualities and what might destroy? The argument here is that as long as reclassification is within the terms of taking with it where the repair activity contests concealment; newness; where it contests the disassociation from reflective action with the hands; where it elevates care, reclassification will retain and possibly amplify pluriversal sustaining worlds. From this perspective it is not the fablabs and maker spaces that are the problem, it's their deliberate reclassification away from repairs decolonial directionality and toward universalising productivism. In transferring, a designer would first identify what is presently classified; is it decolonial? If yes, how does it reclassify while retaining those same qualities in the same geography; or how does it transfer to another geography? Then, what is the appearance; is the repair activity an image of decolonial design; an explicit strategic plan for decolonial praxis; and/or an implicit pragmatic instruction assisting the repair of objects and things?

Amplification: Once designers have identified a transfer gap and reclassification opportunity, exercises in recoding might occur that amplify aptitudes and affordances of climate and conflict migrants, contra-productivist movements, informal resourcefulness, resilience, bricolage and repair. Manzini talks about amplification when he discusses design intervention as 'weak signal amplification' [31], which "calls for the designing of communicative artifacts to make initiatives visible that would otherwise remain hidden". This might take the form of a website, films and documentaries, festivals, exhibitions and events as well as maps, instruction and repair manuals, information graphics and how-to guides. Regardless, as Manzini notes [31] it is a politically value laden judgement. A designer is "choosing the criteria by which to look at social dynamics, and on the basis of which to 'extract' the promising cases" [31]. Relevant to this discussion, this decolonial judgement should be in connection with ontological design and sustainable futures, what Tony Fry calls an imperative of Sustainment [4]. This is to identify structural unsustainability (the negation of time) in the cultural value of repair and take steps to recode it; or identify sign values in repair that sustains (that adds time) and seek to dramatically increase its value in society by recoding. The field of Transition Design also refers to amplification as a key area transition designers work in, "amplify[ing] and connect[ing] grassroots efforts undertaken by local communities and organizations" [32]. Designers might employ amplification methods from these emerging fields while working through the Cultures of Repair Relational Map.

5 Limitations

A subsequent paper will report on the effectiveness of working with the key threads and map in field studies and pedagogical settings, along with other modalities of amplification occurring, such as through the established explorations of Manzini [31] and John Thackara [33], inside and outside cultures of repair. So too, Migration Studies requires a thorough analysis to understand what can be learnt to contribute to this discussion. On the relational map, Bruno Latour famously said the designerly 'drawing' skills of designers could be put into play, not just to design objects, but rather to draw things together, by opening up controversial *things* [34]. An attempt has been made here, but further reflection is needed, via information design scholars, Johanna Drucker [35] and the author's [36] previous work, on the traps that information design and mapping affords.

6 Conclusion

Through a trace concerning the role that modernity and colonialism have played in both destroying and inculcating cultures of repair decolonial design is an emerging field that can engage in the praxis of transferring and amplifying opportunities afforded by cultures of repair in transitioning toward sustainable futures. Four key threads tracing implications associated with repair cultures have been brought to focus here; *concealment; newness; techne; and care*. A further three key threads have been drawn together through which designers might move toward praxis: *transferability, reclassification, and amplification*. An aide to assist designers see and speak of repair in a decolonial context and for this to become praxis is also presented in the Cultures of Repair Relational Map. This is to contribute to a field concerned with ontologically redirecting toward decolonial and sustainable futures, with promising research gaps emphasized in transferring repair knowledge across geographies—from people moving due to climate change and global unsettlement—reclassified and amplified by decolonial design.

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Can Interactive Installations Bring About Behaviour Change? Using Interactive Installation to Change Food Waste Behaviours

Jayati Bandyopadhyay and Girish Dalvi

Abstract Addressing social issues using interactive installations has gained substantial impetus with the advent of new technologies. Public installations can be designed to interact with people in an engaging, non-intrusive manner in order to create awareness and motivate the audience. In this paper, we present a design solution to encourage people not to waste food. This installation is designed in accordance with persuasive theories, and utilizes moderate amounts of coercive feedback. The goal is to motivate people and bring about a behaviour change without being paternalistic in nature, which as an approach often fails to bring about a change in their behaviour. Effect of the designed installation was studied on students of a university. Individual and total food waste was recorded and statistical tests were performed to evaluate the quantitative data, which was further investigated by an online survey. The results of the study show that interactive installations have the potential to bring about behaviour change in people.

Keywords Interactive installations · Behaviour change · Food waste · Persuasive design · Non-intrusion · Trigger · Motivation · Aversion · Coercion

1 Introduction

India, a country with a population of over 1.2 billion people has witnessed massive economic growth over the past few decades. In spite of a significant increase in the Gross Domestic Product (4.5 times) and per capita consumption (3 times) in the past two decades [1], 194.6 million people are undernourished in India and is home to the largest hungry population in the world (15.2% of the population) [2]. There are around 3000 children in India dying every day from illness related to poor

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diet [2]. The food grain production reveals a completely different picture. India ranks first worldwide in farm output [3]. It is the largest producer of milk and second largest producer of wheat, rice, sugar, groundnut and inland fish. Producing adequate amount of food does not guarantee food or nutrition security and is not the only criteria to eliminate hunger and malnutrition. The relation between food waste and hunger do not seem to have a one-to-one mapping; food waste indirectly increases the global food prices [40], which in turn affects people with low access to food.

Multiple initiatives have been started, across the world, to address the food waste problem in different stages of production and consumption [4–9]. Some of these solutions are working well to manage unused or excess food at a production stage, However, leaving food on the plate is a behaviour that needs to be changed at an individual level. We reviewed literature on behaviour theories and persuasive design techniques to understand food waste behaviours.

Behavioural economists suggest that humans are not only irrational, their irrationality is highly predictable. Further to this, informing people about their own behaviour can improve the quality of rational decisions [10]. Researchers in HCI and behavioural sciences are increasingly exploring the use of technology to support behaviour change in various domains such as health and sustainability [11]. HCI researchers have used behavioural theories to make design decisions about the technical systems, to guide qualitative evaluation and to define users [11].

In this paper, behavioural theories were primarily used to address the design of an interactive installation—The Darker Side, focused on lesser known facts on impacts of food waste in India. The installation attempts to address the habitual behaviour problem of leaving food on the plate, which in turn tries to make a case for the use of interactive installations to bring about behaviour change.

2 Related Work

Habitual behaviours are performed without active thinking. These occur when there has been a high-frequency history of the behaviour [10]. People do not pay attention to food waste and its disposal as they perform it as a routine task [12, 13]. Persuasion and motivation [14] have been identified as some of the triggers to break the habitual cycle. According to Fogg's behaviour model for persuasive design, three factors essential to bring about a behaviour change are ability, motivation and trigger. In case of food waste, while individuals possess the ability to reduce waste, they might not be motivated to change their food waste behaviour. If individuals have both the ability and motivation to do so, timing and placing an effective trigger near an appropriate location might induce the change.

Consolvo et al. [15] derived eight guidelines for designing technologies for lifestyle change. According to them, such technologies, need to be abstract, reflective, unobtrusive, public, aesthetic, positive, controllable, comprehensible to users, and they must include historical data. The BinCam experiment [10] was conducted to improve recycling behaviour within a closed homogeneous group. The authors describe a design which attempted to raise awareness through social influence and aversion effect. They argue that social influence results in self reflection and causes a 'feeling of shame'. Although BinCam could not effectively influence user behaviour, social influence and gamification have been identified as possible methods to motivate people to change their behaviour.

Similar projects of inducing behavior change on social issues include Cleanly [16], a gamified urban trashducation system, which aimed at creating awareness about environmental pollution. The trash track project [17], created awareness about the waste removal system by using tags to track in real time and visualise the journey of individual trash objects. The World's Deepest Bin [18, 19] used audio feedback to prompt reflection on waste disposal.

The piano staircase [39] was an attempt to make people do physical activities through playful persuasion. In [20], the authors attempted encourage exercise in public spaces through the use of a Kinect based interactive installation which enabled the users to perform upper body Tai Chi movements.

There have been attempts to motivate people to perform physical activities [21], reducing electricity consumption [22], improved waste disposal and management [10, 16–18] using playful persuasive techniques and contextual information displays. Generating awareness about serious social issues such as domestic violence [23] have also been attempted through interactive billboards, where cameras detected faces looking at the billboard and morphed the visuals. Even though most of these installations were successful in engaging the audience and achieving the 'target behaviour' at that point of time; there seems to be little work done on evoking self-reflection and sustaining the behaviour change among users.

Using design to change user behaviour for social benefits has also been identified as an upcoming trend [21, 24]. 'Design with Intent' (DwI) [25] is an approach where patterns help designers to 'Design for Behaviour Change'. 'Change the campus with fun' [26] is an implementation of DwI, implementing 'fun theory' in their service design, considering various social and sustainability factors. It suggests that gamification can induce playful triggers, which will not only help to achieve 'target behaviours' but also make them habitual or customary. Awareness raising [27] and presenting contextual information [28] has also been identified as a key stage in the processes of behaviour change as it stimulates self-reflection.

Ybarra and Trafimow [29] suggest that sense of group results in conformation to social norms, where the individual is motivated by the desire to obtain social approval and avoids rejection by others [30]. This might not result in true internal change in behaviour as individuals can behave superficially when under social surveillance.

According to Fogg, persuasion should not be coercive, manipulative or deceitful. It should allow individuals to remain in control of their own actions [31]. Although, the use of coercion in persuasive technologies has been questioned and excluded by Fogg, Kirman et al. [32] and Foster et al. [33] have argued that constructive aversive feedback and lighter forms of punishment can support behaviour change.

Nonetheless, coercive strategies need to be designed carefully such that they do not disengage or intimidate users.

'Nudges', are considered to be soft, unobtrusive type of strategies, which influence people to change their behaviour [34]. 'Libertarian Paternalism' helps individuals to use their 'Reflective System' of thinking (Rational, Controlled, Self-aware, Rule-following) during decision making.

Through this short review, we can assume that, installations can be used for playful persuasions [21] and can be designed to be non-intrusive, thereby a potential medium to bring about behaviour changes. However, a 'one-size-fits-all' approach might not work well [35] and hence performing user studies to understand the audience could bring up insights which help in taking design decisions for the intervention.

3 Primary Research

The university in which the experiment was carried out was a fully residential institute with in-house dining. The selected hostel housed the largest mess in the campus and served around 2000 students. The mess was operated on a contract basis. The services provided by the contractor broadly included cooking, distribution of food, cleaning and maintenance of the mess. This mess was selected for two primary reasons—it was the largest mess in the campus and the mess coordinators were already motivated to reduce food waste. The mess had posters asking people to stop wasting food and a white board where food waste statistics were updated after each meal. These evidences indicated that certain stakeholders were already motivated and a trigger might help in bringing about a behaviour change.

Before commencing user studies, different stakeholders of the mess and their roles were identified, namely, Students, Mess Staff, Mess Managers, Mess Student Coordinators. Semi-structured interviews were carried out and different key questions were designed for each of these stakeholders. Seven students, two mess workers, one mess manager, one mess coordinator were interviewed. Students were asked questions to understand their food waste behaviours, the mess manager and workers were interviewed to understand the supply chain, waste and excess food management.

Students showed resistance to answering questions about food waste. Individuals, wasting food, were selected and interviewed in an attempt to understand their food waste behaviours. The approach was to empathise with them; conversations were initiated by asking questions about the quality of food. Most of them blamed the quality of food for their wastage; a handful of them accepted overestimation of their eating capabilities to be the reason. Students complaining about the taste of food were further asked to objectively categorise their reasons for disliking the taste, as too salty, spicy, bland, sour etc. The responses received were mixed. Each interview lasted for around five minutes, this indicated that the students were not keen to spend time to elucidate their behaviour.

The user journey and layout of the mess were studied to decide the position of the installation. The placement of trigger had two potential options—the food counter and the dustbin. Placing it near the food counter would ideally have motivated them to take food wisely, but the queue for the food and limited space were major drawbacks. A crowd gathering near the counter would add to the chaos during rush hours. Moreover, hungry students would not have wanted to engage with the installation. Hence, the space surrounding the dustbin was selected for the installation.

Major observations and insights drawn from the primary research were: students did not have loss aversion (a tendency to strongly prefer avoiding losses) [34] when it came to wasting mess food as they considered it to be equivalent to free food. While some students were motivated to reduce food waste, they limited themselves to putting up posters, which, probably did not create much of an impact. Most of the students did not consider tasting as an option before taking a larger portion. As the food counters were placed at extreme corners of the mess, they tended to take large amounts of food to avoid coming back for further helpings. These observations and insights were analysed, collated and used to build design ideas. Each design idea intended to solve multiple problems identified during the primary research by using the insights gained through literature review and user studies.

4 Design of the Installation

Positive and negative (‘Pleasure’ and ‘Pain’) motivations were explored while developing the message to be put across. Playful persuasion and gamification were also considered as possible options for intervention. In order to raise awareness through the installation, the option of presenting facts related to food waste and hunger were also examined. The motivated students could also be made a part of the design solution to create social influence on the less motivated students.

A small scale pilot installation was implemented to validate initial design ideas, test the hardware, get initial feedback and suggestions. It also helped in understanding the space and finalising the position of the installation.

The design decisions focused on facilitating awareness about the ill effects of food waste. The strategies applied were ‘gaze effect’ (Gaze Effect: the awareness of any object can induce an awareness of also being an object) [36] and ‘panopticon’ (Panopticon: a feeling of being observed, under surveillance) [37]. A poor hungry Indian child staring at the camera was selected to be the subject of the visual, as people are generally more concerned about children than grown ups [38]. It also induced among the audience, a sense of being observed as a subject. The messages were designed to evoke pain and give a moderate level of aversive feedback. The messages changed from low to high level of aversion depending upon the amount of food thrown (wasted) by an individual. The changes in the messages were kept subtle to make the installation incidental in nature. The statements used for negative motivation were an attempt to articulate the behaviour of students towards food as understood during primary research. The quantitative data captured before and after the pilot-installation was not significantly different but it attracted a lot of attention. The audience found the concept of reducing food waste through an installation intriguing. They were also interested in the technical nuances, enthusiastically gave suggestions as to how the hardware and visuals can be further improved. Taking cues from the pilot implementation, the main installation was put up on a larger display with improved visuals, messages and hardware.

4.1 The Final Installation

The final implementation was designed to detect proximity and faces of the audience. The food waste data was measured through a weighing machine on the dustbin which was connected to a Raspberry Pi and projected on a wall mounted display. In a college mess, the minimum screen size was decided to be 40 inch which was an observation made during the pilot implementation. A flat arrangement for the screen and the dustbin was aimed to facilitate self reflection through the awareness facts, contextual information and visuals. The installation was named ‘The Darker Side’ highlighting the lesser known facts about food waste and hunger issues in India.

The visuals projected on the screen changed only for users who (wasted) threw above a certain amount of food into the dustbin. For others, the screen displayed only the total amount of food wasted. A minimum threshold of 100 grams was decided to eliminate instances of inedible leftovers being dropped. The threshold was decided after analysing the data captured during the pilot implementation.

The visuals had three components: Awareness facts, Contextual data, and Interactive visuals. The awareness facts were related to the plight of farmers and malnourished children in India. They raised questions about the attitude of the students towards mess food, and reminded them that they were a privileged section of the country. The messages (Fig. 1) were aimed at giving aversive feedback and were constructed such that they highlighted the undesirable behaviour. The contextual data projected the total food wasted in the mess and food wasted by that individual at a particular point of time. This data reinforced the need for cognisance and the urgency to change the behaviour of wasting food on plate.

The images (Fig. 2a) portrayed the underprivileged population and complemented the awareness messages. The subjects, being close up portraits of people staring at the camera, if closely observed were not static. The image changed based

Fig. 1 Messages with facts, aversive feedback, highlighting in *red* the desired behaviour

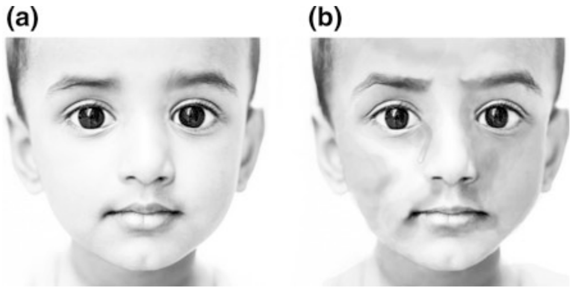

Fig. 2 **a** (*left*) Static visual of a healthy child. **b** (*right*) The visual changes, the face of the child morphs into a malnourished child when food is thrown in the bin. *Source* Flickr

on the amount of waste thrown into the dustbin. This contributed to the incidental attribute of the installation. The facial expression of the subjects changed (Fig. 2b) (happy to sad, healthy to malnourished) according to the amount of food thrown which was thrown into the bin. The time of the transformation was manipulated by observing the average attention span of the audience; five to eight seconds for the mess under consideration. The background was white and the images were grayscale. This was done to reduce elements which might distract the audience.

5 Evaluation Protocol

In order to understand the effectiveness of the installation, both quantitative and qualitative evaluation approaches were adopted. The experiment was designed to collect individual and total food waste in pre (control data) and post installation phases. The data collection was carried out in three stages: pre-installation, installation and post-installation. In the pre and post installation stages, food waste data was collected without the installation during lunch and dinner (3 hours for each meal). In the installation phase, the installation was put up for lunch and dinner. Different set of visuals were chosen for the two meals to maintain audience engagement. An online survey was prepared and administered in the post-installation stage. This survey had 15 closed and 2 open ended questions. Some of the questions in the survey were:

- How interesting did you find the installation? (evaluating installation as a medium)
- Do you think that the installation was effective in spreading awareness? (effectiveness of installation in spreading awareness)
- Do you think it motivated you not to waste food? (effectiveness of installation in motivating audience not to waste food)
- Do you think the system has helped you to take informed decisions regarding food waste? (effectiveness of installation in breaking habitual behaviour cycle)

The overall impact of the installation and its sustenance were measured through:

- Do you get reminded of the installation when food waste is being discussed?
- Do you get reminded of the installation when someone wastes food?

Demographic information was also recorded with the possibility of drawing inferences based on change in behaviour according to age, education etc. The objective questions were in the form of a 5 point likert scale which were quantified and evaluated using standard statistical methods.

6 Results

The installation was put up for a limited period of time and there were multiple variables contributing to the food waste for any particular day at the mess. Collecting food waste data for a longer period of time would have neutralised the outliers within the dataset. One of the major challenges was that the menu was different across the meals making it difficult to evaluate the effectiveness of the installation through quantitative data. The total and individual food wasted collected across the meals during the pre and post assessment phases were not significantly different. Hence, survey data was given more weightage during evaluation. An anonymous online survey was circulated within the hostel and we received over 250 responses. These responses were cleaned and statistical tests were performed on around 200 responses.

The quantitative results from the survey data indicate 'towards positive' results:

The responses to questions related to, 'Motivating the audience not to waste food through installation' with the responses to questions on the 'effectiveness of installation in spreading awareness' had a Pearson correlation of 0.7245.

The question: 'How interesting did you find the installation?' had a median score of 4, on a scale of 1 to 5 (1 = not at all interesting, 5 = extremely interesting). 95% confidence interval of the mean was 3.45–3.75 with standard deviation (SD) = 1.09.

The question: 'Do you think it motivated you not to waste food?' had median score of 4, (1 = Strongly Disagree, 5 = Strongly Agree). The 95% confidence interval of the mean was 3.3–3.64 with SD = 1.20.

The question: 'Do you think that the installation made you more informed about food waste?' had a median score of 4 (1 = Strongly Disagree, 5 = Strongly Agree). 95% confidence interval of the mean was 3.31–3.63 with SD = 1.29.

Some questions did not indicate a statistically significant trend but the qualitative feedback was encouraging, as the students voluntarily provided multiple design ideas in the open ended question. Students also volunteered to join the initiative of reducing food waste. Some of the feedback received was:

> Figures showing empty plates—ticked as 'You have done a good thing'; Plates with a little remaining food-ticked as 'OK'; Plates with a considerable amount of food remaining as 'You are doing it wrong'. Little quotes may also help near the food distributing table like: 'Take what you want, eat what you take'.

> A big projector screen should be used instead of an LED screen so that people can see what's going on while having their food. This will certainly make them not to leave food in their plates. A video can be made about food wastage with real footage (without showing faces) and circulated among residents.

More than 50% students mentioned that they were reminded of the installation when food waste was being discussed or someone wasted food after the installation was permanently removed from the mess. People gathering near the installation, audience engagement, motivated the students to explain the concept of the installation to fellow students and added to the positive feedback. The quantitative results of the survey and the qualitative feedback reinforce the possibility of using interactive installations to bring about behaviour change.

7 Conclusion

The main aim of the experiment was to understand whether a positive correlation can be drawn between interactive installations and behaviour change. The uniqueness of the installation designed lies in the use of aversion and moderate coercive feedback combined with persuasive techniques. The experiment was conducted on a heterogeneous group of students having diverse socio-economic and cultural backgrounds. The installation was put up for a short period of time and the statistical results of the post-experimental survey indicate a 'towards positive' trend. The preliminary statistical inferences along with the qualitative feedback indicates that interactive installations have the potential to bring about behaviour change.

This experiment is just the first step towards bringing about a behaviour change pertaining to social and environmental issues. Some of the persistent challenges include, finding a sustainable solution to the food waste problem, expansion and scaling up in different contexts, attracting and retaining attention of the audience when implemented over a larger span of time. The future scope of work includes implementing an ecosystem around the installation, increasing the sustainability of the solution and cost reduction of the setup.

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Review on Sustainable Lighting Design in Art Galleries to Balance Between Visibility and Conservation of Light Sensitive Art Exhibits

Amrita Bhattacharjee and Swati Pal

Abstract The core function of the Art gallery is art exhibition as well as conservation. Protection of light sensitive exhibits from damaging effect of light while maintaining the higher exhibition quality with respect to visibility is a key concern in lighting design of art galleries. The conflict between light level for visibility of exhibition from viewers' perspective and conservation of artifacts creates philosophical dilemma for lighting design in art galleries. So, a review of literature has been done in this regard as this conflict still exists. The existing recommended light level for the art galleries from the view of conservation and the need for verification of this existing light level for better visibility have been discussed. As a consequence, this review of literature will help to find out the need of further research so that balance between visibility and conservation of light sensitive art exhibits can be done properly by lighting design of art galleries.

Keywords Art galleries · Lighting design · Visibility · Exhibition · Conservation

1 Introduction

Art galleries collect, preserve, analyse, and display [1] various artefacts which are often unique in size, shape, texture and colour. Though light is one of the aspects of art gallery design [2] but many of the exhibits are extremely sensitive to light damage. Thus effective exhibit lighting design must balance required visibility level for exhibition and conservation needs [1] simultaneously. Exposure to light in all forms causes a chemical reaction to happen within the molecular level of an artefact [3]. Light exposure can cause textiles to weaken, paints to darken or change colour and paper to become weak, bleached, yellowed or darkened. The best preservation practice would be to house all artefacts in complete darkness whereas the exhibition need of art galleries is failed in that case. As recognized by the International

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Commission on Illumination (CIE), an object poorly seen is partially wasted [4]. So, this conflict between two fundamental functions of exhibition in art galleries creates the philosophical dilemma of lighting. High standards of conservation may lead to poor conditions of exhibition [5]. On the other hand, a visually comfortable ambiance for exhibition may expose valuable objects to lower conservation standards. However, this area need more research as the dilemma still exists. In view of this a literature review has been done to focus on the present situation and existing recommendations in this area of conflict.

2 Methodology

To fulfill the objectives of this study a systematic review of the English-language literature has been conducted from various books, journal papers and conference proceedings. The combinations of the terms "exhibition", "lighting design", "visibility", "light sensitive", "preservation" has been used to accelerate the search engine for identifying the conflict between art exhibit display and preservation in context of lighting design. The purpose of this study is to reveal the existing light level in art galleries for exhibition and further need of research regarding this. This present literature review sought to examine the light level for proper display of art exhibits, so, articles dealing with the process of exhibit preservation were excluded. As light level for visibility of exhibition has been considered in this study so, articles dealing with whole environmental lighting of art galleries were excluded. By following these inclusion-exclusion criteria among 82 articles finally 27 articles has been taken in consideration for this review process. A detail about light level for visibility in perspective of viewers' comfort has also been reviewed through this study.

3 Results

Primary responsibility of an art gallery is to take care of its collections with the effective public display. Thus, lighting design for art galleries should include exhibits' protection and the proper visibility level in the course of visit. Lack of effective lighting may lead to most interesting collections and important displays ineffective. On the other hand, in order to cause the minimal damage to light sensitive artifacts, minimization of the exposure of the artistic production with the electromagnetic radiation is required [6–9]. According to CIE, the maximum illuminance level on highly susceptible materials is 50 lx [1] (Table 1). It has been found that similar illumination level has been recommended in French and Japanese recommendations [10]. Also, according to Indian standard (IS: 3646) the maximum illuminance to be provided on the principal plane of the highly light sensitive object in art galleries which has been classified as same as CIE classifications is 50 lx [11].

Table 1 CIE recommended total exposure limits in terms of illuminance hours per year

Types of material	Maximum illuminance	Lux-hours per year
Highly susceptible displayed materials: textiles, cotton, natural fibers, furs, silk, writing inks, paper documents, lace, fugitive dyes, watercolors, wool, some minerals	50 lx	50,000
Moderately susceptible displayed materials: textiles with stable dyes, oil paintings, wood finishes, leather, some plastics	200 lx	480,000
Least susceptible displayed materials: metal, stone, glass, ceramic, most minerals	Depends on exhibition situation	–

It has been proposed through an experimental study that viewers will find 'pleasing' in high correlated colour temperature (CCT) illumination at high illuminance and low CCT illumination at low illuminance [12]. In succession it has been shown that viewer preferred warm (2800 K) sources at low intensities [13] and also the boundary at which human eye lost its ability to see small colour differences occur near 2 lx [14]. It has been cited that colour discrimination by human eye can be performed at about l0 lx [15]. The data on viewer satisfaction with lighting in a gallery has been described and it was explored that most of the satisfaction is reached by 50 lx [16]. Thus, the illuminance level in art galleries should be regulated to a low value to keep the colour fade damage as low as possible. On the contrary, according to Hunt Effect [17], the brightness and colourfulness of chromatic objects decreases when illuminance decreases. It has been discussed through experimental study that recommended illumination level for art galleries should be increased under specific situation for proper visibility [18]. The 'situation-specific resolutions' [19] for lighting design in art galleries which include balance between requirements of visibility level with the conservation of art exhibits has also been discussed. Such situations include artifacts with low contrast details, dark surfaces, where complex visual searches may be required within a limited time and for older viewers. At present only the Canadian Conservation Institute [18], has appeared to implement it in their lighting recommendations in the form of higher light levels for enhancing the experience of the visitor under a few specific circumstances. However, to limit the overall light exposure, compensation in exposure time (Lux-Hours) has been applied depending on the objects belonging to one of three sensitivity classes as mentioned in Table 1. An experimental study on LED sources partially conflicts with the earlier findings regarding viewers' preference for illumination level [12] and it indicated that low illuminance at lower CCT is pleasant for viewers is not acceptable in case of LED lighting [20]. This experimental result was implied with findings of earlier research on illuminance level for viewer [21]. From an experimental study on Blue Wool Standard swatches (BWS) (ISO1, ISO2 and ISO3 grades) and natural dyed silk fabrics, it was found that LEDs caused a slower fade than conventional halogen lamp [22]. Study focused on photo-degradation of artifacts due to light sources it was concluded that the LED lamp with high illuminance produces minor degradation compared to other conventional light sources [23]. The behavior of the different light sources (CIE standard illuminants) regarding damage on paintings (Paleolithic cave paintings) has been compared and it was found that LED provides very low values of the effective radiant exposure and a better colour perception than that obtained with all the other considered light sources [24]. Also, by analysing the experimental study performed on different sample paintings (oil painting, watercolour, textile), it was found that the photochemical degradation of art exhibits is lower in the case of RGB LEDs than with other conventional light sources [25]. So, the existing recommended level of illuminance might be increased in case of lighting with LED, which in turn will increase the brightness and colourfulness of the art exhibits. Again, from the experimental result carried out on Japanese Paintings (mosaic colour samples of Red, Yellow, Green, Blue natural mineral pigments and Gold leaf) it was found that the subjective feeling under RGB LED at 10 lx is almost same as with white fluorescent lamp at 700 lx [26]. Also, from the review of museum lighting already done by researchers, it has been found that exhibition part of art gallery lighting need to receive more attention [27] due to lack of study with the introduction of LEDs in lighting field. So, it is required to review the recommended light level for art galleries with the advancement of light sources to have sustainable lighting design for better visibility of exhibition from viewers' perspective while maintaining the conservation issues of artifacts. This present study of literature will certainly help to consider more research in this field of interest.

4 Discussion

From review of literature it can be said that maximum limit of illuminance level for light sensitive artifacts has been referred as 50 lx [1, 10, 11], by different countries recommendations in view of conservation of artifacts in art galleries though there is atmospheric variation (e.g. temperature, humidity) among different countries. Earlier researchers have argued this recommended level as enough visibility level for colour discrimination [12–16]. However, 50 lx has been proven to be well for colour perception, but viewer comfort for visibility has not been considered in these earlier studies.

The higher level of illumination has been proposed under specific circumstances [18, 19]. In each of these cases, up to three times the basic recommended light intensity (50 lx) can be employed ideally compensating by proportional 'dark periods' as suggested. However, these studies maintain the recommended Lux-Hours which are mentioned in Table 1. Thus, only the visibility level has been enhanced in specific circumstances but whether standard recommendation level can be modified with the advancement of lighting technology and sources has not been discussed.

When viewers' perspective was considered it contradicted [20, 21] with the earlier finding [12] of viewers' preference of low illuminance at lower CCT. However, these experimental studies have not discussed about what should be the preferred light level for viewer with respect to comfort of visibility.

Previous study carried on standard BWS has shown that BWS faded slower under LED with the highest CCT and faster under halogen lamp [22]. In spite of that in the analysis part of this study authors have questioned whether the use of BWS as light dosimeter as reported in several standards on preventive conservation is still effective for LEDs or not. Also, it was found from experimental results that CIE metric to assess damage indicates a higher risk of damage related to LED with higher CCT, whether, radiometric analyses showed that for LEDs higher CCT is not directly related to higher UV content, as in traditional lamps. So, further research and testing are needed to assess damage metric and reference dosimeters to standardize the light level for visibility in art galleries.

The analysis of Infra Red (IR) and Raman spectra show that the LED lamp produces slower degradation to the artifacts than that of other conventional light sources [22]. Also, from the detrimental effects of different light sources on paintings it has been observed that LED causes less temperature rise and change in relative humidity as compared to other conventional light sources [25]. So, the cracking of paint, i.e. the damage which is caused by continuous heating and fading of colour i.e. photochemical degradation of the surface which is caused by moisture content, is lower in the case of LED [24] than with other light sources. It has also been found that LED provides very low values of the effective radiant exposure compared to other conventional light sources. So, the existing recommended level of illuminance might be increased in case of lighting with LEDs for art galleries which will increase the brightness and colourfulness of the paintings satisfying the cause of Hunt Effect. However, these experimental studies were not performed from visitor's perspective to determine the visibility level. So, further research is needed to justify the visual comfort of visitor by maintaining the balance between visibility level and conservation of art exhibits in art galleries.

From above discussion it can be said that future research need to be focused on illumination level for proper visibility of art exhibits from cognitive perspective of viewer while maintaining the preservation issue simultaneously. Laboratory experiments on viewers' choice for level of illumination on painting need to be done in consideration of other parameters associated with light sources. Both qualitative and quantitative approach has to be taken to make a proper guideline for balancing between visibility and conservation issue of light sensitive artifacts.

5 Conclusion

Allowing visitors to view displays is a core role of exhibitions. However, light can cause damage to artifacts, which violates the goal of preservation. For a sustainable design for exhibition in art galleries light damage should be minimized but at the same time proper visibility for the displays should be maintained by providing standard light. To mitigate this existing conflict between exhibitions versus preservation of light sensitive artefacts of art galleries further research is necessary. The future research will help to establish the light level for art galleries so that the lighting design in the art galleries will be able to present a visually comfortable exhibition while preserving artefact life as long as possible for the sake of common artistic interest.

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Meghalaya Tourism: Inculcating Cultural Image in Developing Enroute Mini Halts

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Abstract Tourism has become a core interest in developing inter-community interaction and harmony between guest population and local host; it shares a lot about the place, the people, their culture and their lifestyle. Meghalaya Tourism fails to focus on the lesser known locations that have the potential to be used for tourism purpose. Literature seems to throw its focus on the popular final destination or tourists spots alone but very less focus is given to the Journey that leads to these spots. This project studied the possibility of introducing mini-halts or stopping stations on the way that connects Guwahati and Shillong to create a travelers' companion experience and provide them with a positive vibe as per their expectations. A pilot investigation on some tourists visiting Meghalaya to gather information on their opinion and suggestions of such enroute mini halts is done. Hofstede Models of Culture and Hofstede's Onion diagram are studied.

Keywords Meghalaya tourism · Enroute mini-halts · Journey

1 Introduction

Meghalaya also known as "The abode of clouds" is famous for being the wettest place on earth receiving the highest amount of rainfall. The state is blessed with the beauty that nature can ever offer be it in terms of the moderate weather conditions, the beautiful landscape comprising of hills and deep valleys and not to forget the

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cheerful and amiable people. The state has a very rich and unique culture and heritage which makes it all the more admirable.

The state government though has taken a number of steps to improve the tourism sector yet it is at the nascent stage and has a long way to develop. It is observed that air and road connectivity, infrastructural facilities at tourists' sites in terms of accommodation, transport, banking including credit card use, drinking water, sanitation, health care, etc. is either lacking or not developed or deplorable [1]. Regarding the information and tourists' servicing it is observed that there are no proper sign-age or guide maps.

Even so tourism strives towards providing the best facilities for its tourists and in doing so it helps in the development of the infrastructure of a place, brings productivity in its economy and has an overall impact on the place's progress and civilization. It is seen that the traveler's anticipation to reach his or her destination can sometimes be followed with body strain, car sickness and even psychological stress. These factors can often ruin the tourists' excitement and bring down their overall expectation. So instead of focusing on the destination alone, what if there is a change in the whole convention and opportunities are open to add value to the journey that leads to the particular place of interest or a new way to inculcate a promising, encouraging and a positive vibe that affects both the behavioral and physical aspect of the tourists before they even reach their destination.

The aim of the study is to analyze the cultural entities of Meghalaya and inculcate them in tourism in an abstract form as the tourists travels the long journey on the Shillong-Guwahati road and the application of the "Hofstede model of the levels of culture" where cultural elements were extracted which can be further used to design any product in the form of souvenirs or to be incorporated in different ways to introduce the culture of Meghalaya.

2 Literature Review

2.1 Tourism and Cultural Tourism

Tourism has been a major social phenomenon of societies all over the world. It is driven by the natural urge of every human being for new experiences, and the desire to be both educated and entertained [2]. The actions of tourists, their desires to consume similar products as local residents and their demand to share the same facilities result in the entire community sharing the benefits of tourism development [3]. Three discrete types of tourists resources exist. They are natural resources such as land, air and water, man-made resources including the built up heritage and cultural resources [4].

According to the scientific definition by cultural anthropology, culture is the totality of a society's knowledge, ensuring the cohesion and survival of the human community. It provides a guideline about the general standards and values of everyday life [5].

Culture is the sum of total of the learned behavior of a group of people that are generally considered to be the tradition of that people and are transmitted from generation to generation. Culture is a collective programming of the mind that distinguishes the members of one group or category of people from another. Culture is communication, communication is culture [6].

Culture is “that complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of society”, that can be specifically be used as features for tourism Plan [7].

In case of defining culture as an attraction, 3 main types are to be distinguished [8]:

- inert culture (e.g.: buildings, architectural styles, artistic creations, personal goods);
- everyday culture (e.g.: leisure activities, lifestyles, gastronomy); and
- enacted culture (e.g.: festivals, carnivals, traditional events).

Culture is composed of patterns of shared perceptions and beliefs that determine the world view and the behavior of members of the cultural group [9].

Thus Cultural Tourism has taken a shape on how ethnic identity elements can be shared and at the same time be expressed.

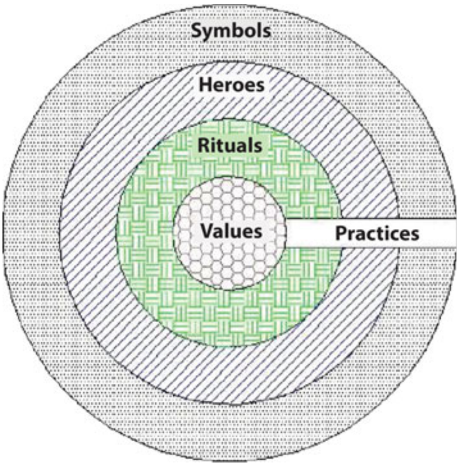
In a narrower approach, cultural tourism is travelling with a cultural motivation. “it is traveling with the motivation of getting to know new cultures, participating in cultural events or visiting cultural attractions in a context where the attraction represents the unique, special culture of the visited destination” [10].

Cultural tourism protects cultural heritage and improves the quality of life of residents and visitors. Linking tourism with heritage and culture will benefit the local economy. The main idea in cultural heritage tourism is to save urban heritage and culture, to share it with visitors, and to reach economic benefits [11].

2.2 Relevance of Hofstede’s Model Cultural Tourism

Enroute to Shillong from Guwahati a few shops and restaurants that supports tourists’ convenience has been studied. People who take rest and eat at these places were selected randomly for their feedback and opinions. Based on such survey the enroute convenience facility concept was proposed and the Hofstede Model was cross checked. This study finds a way to extract cultural elements and implement it for the concept of introducing culture to the tourists. The Hofstede model of the levels of culture explains the different levels of culture in a society and explains as to what is included in these levels. This is shown in the following diagram which is known as the Onion diagram.

Fig. 1 Hofstede onion diagram. *Source* Cultures and organizations: software of the mind



Hofstede in this concept of Onion Diagram tries to show the "Manifestations of culture at different levels of depth". He states that "Cultural differences manifest themselves in several ways—symbols, heroes, rituals, and values" Fig. 1.

According to Hofstede the core of a culture is formed by the values as shown in the diagram. The different levels of culture will be the rituals, the heroes and the symbols. These are described as follows:

Symbols are words, gestures, pictures or objects that carry a particular meaning which is only recognized by those who share the culture. The words in a language or jargon belong to this category, as do dress, hairstyles [12]. New symbols are easily developed and old ones disappear. Symbols can be changed, imitated and replaced by others. For this reason, they are the most readily discernible, outer layer of layer [13].

Heroes are persons, alive or dead, real or imaginary, who possess characteristics which are highly prized in a culture, and who thus serve as models for behavior.

Rituals are collective activities, technically superfluous in reaching desired ends, but which, within a culture, are considered as socially essential: they are therefore carried out for their own sake. Ways of greeting and paying respect to others, social and religious ceremonies are example.

The core of culture is formed by values. Values are broad tendencies to prefer certain states of affairs over others. Values are feelings with an arrow to it: they have a plus and a minus side [12]. Values represent the basic conceptions that people have about how things should be and therefore shape the development of certain personality traits and particular behavior of individuals in a society [14].

Practices include all the three viz. Symbols, Heroes and Rituals. These can be taught and trained through practice unlike the core values. These can be discerned by an outside observer although not fully comprehended, but rather only interpreted in particular ways [15].

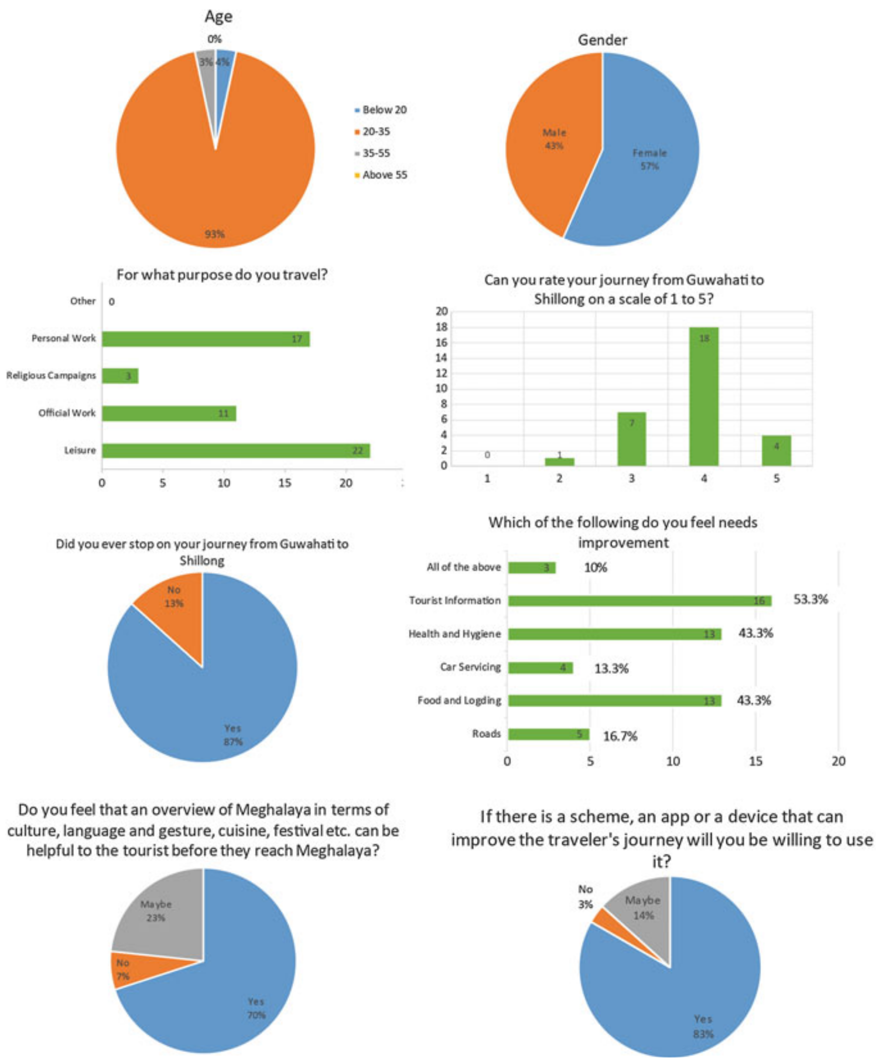


Fig. 2 Graphical presentation of data

The Onion Diagram is also in correlation with other models proposed by Hofstede. A few authors have given the following critiques on Hofstede's models.

- In-built western bias (e.g. the dimensions are chosen from a western point of view)
- A variety of methodological problems (e.g. Questionnaires measure self-representation, not practice)

The target of the critic is not as much Hofstede as the simplified and uncritical use by others of his concepts [13].

3 Methodology

Case studies was done on places in India and Thailand where Cultural Tourism was adopted. A pilot study was also done on a few of the tourists and locals who travel the GS road or the Guwahati-Shillong and the feedback collected was studied. A semi-structured questionnaire was sent to 30 participants both male and female of the age group ranging in between 20 and 55. The roads and the infrastructure were also studied and pictures were taken.

4 Results and Discussion

4.1 Data Collected

A few of the data collected from the questionnaire are shown below.

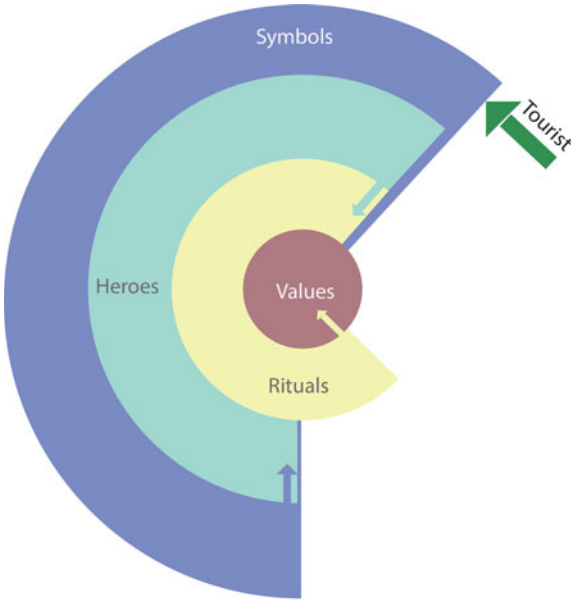
Case studies on the places which have adopted Cultural Tourism were also be referred. These include Rajasthan also known as “The Land of Kings”. The rich culture and heritage of State was explored and use to promote Tourism. A sense of the ancient fills the place, from the potent aroma of its cuisine to the dancing and brightest colors of its native costumes. The next case study was done on Kerala. The Kerala Tourism Industry has managed to involve and indulge the tourists in experiencing its culture. Be it on its local cuisine, art or even its Ayurvedic Holiday package they are able to offer the tourists with the best features of their culture. The next Case Study was done on Thailand also known as the land of smiles. They are able to find out the “Cultural Identity” of Thailand. Using pictures and applying the PCA Technique, they are able to classify the different features that describe Thai Culture, like Thai Antique, Thai Relax, Thai Traditional, Thai Unique [16].

An interaction was done on a few of the tourists and shopkeepers of the enroute mini-halts were studied. The Roads and the infrastructure were also studied. The pictures of the Shillong-Guwahati road are shown below Fig. 3.

In Fig. 4 the last picture depicts one of the traditions of the people in Meghalaya where they offer “*kwai”* which is areca nut as a token of love or welcoming. These are some of the examples that the tourists can see or focus as they are halting at the places for eating, resting etc. There were also some interactions with the shop-keepers and the tourists. This led to an idea of what the tourists want and prefers. The shopkeepers mention about how the tourists spends their time in the shops, which time of the year the number of tourists is high and facilities they offer.

Fig. 3 Shillong-Guwahati road and the mini-halt or stopping points

Fig. 4 Proposed model



4.2 *Proposed Model*

The Hofstede Onion Diagram explains clearly about the different levels of Culture.

Using this model as a guide a model of creating these cultural dimensions among the tourists as they travel on the road from Guwahati to Shillong was proposed.

The journey starts as the Tourists leaves the airport or Railway station and continues as he moves towards the State in a way that he or she should be able to distinguish it from the other states by seeing things around.

According to this Diagram, the tourists travels from the outer blue circle to the inner red circle. This in practice is related to the tourists traveling from Guwahati to Shillong. As he moves inward he imbibes and experiences the various practices related to the culture of the State. There would also be a Tourism Centre where people can have an interactive communication with a software generated avatar with the features of the people of the state to learn the language, basic words and gestures of the local people. As the tourists enters the outer circle and as they move towards the inner circle they grasp the culture of the State from the symbols, heroes and rituals. Finally, it is expected that they attain the values as being a part of the culture when they arrive at Shillong and carry it with them when they leave. Symbols are placed in the outer circle because at first they need to understand the locals in terms of their expressions, languages etc. As stated earlier in the literature review, these can be easily imitated. Next comes the heroes, the tourists will need to know about the stories of the legends and idols, the fictitious characters known within the place. To understand rituals an exposure to the history is needed. Rituals are non-utilitarian activities which governed by rules [17]. To partake in the activities of a ritual, knowledge of symbols and heroes is needed. Finally, the values which constitutes feelings, appreciation and satisfaction comes into place. These values are expected to be a small part of their understanding of their journey.

4.3 Formulating Cultural Elements

In this study the "Cultural Elements" in the form of Symbols, Heroes and Rituals were formulated. The Symbols were extracted based on the common gestures and the lifestyle of the people. The Heroes relate to most of the Legends and freedom fighters, like Kiang Nangbah, Tirot Sing, the khasi folk tale on the famous hero Manik Raitong and the famous Khasi poet Soso Tham. The rituals include the different festivals and ceremonies like the Behdienkhlam, the Wangala dance of the Garo Tribe, The Shad Nongkrem and the famous bull fights. Using these Cultural Elements different products or design features can use these as their inspirations Fig. 5.

Fig. 5 Cultural elements

Table 1 Feedback of participants

(1) (a) A lot of accidents have to lead to some solution for their prevention. (b) Landslides need to be prevented if possible (c) *Information* on places to eat, sometimes the cab drivers stop at places they've been asked to (d) *No information* of Meghalaya, when people go there to travel. Usually it falls down to the cab drivers who usually don't do a good job
(2) Hangouts; (3) Highways are not well-lit at night; (4) *Roads signs* (About places, vehicles)
(5) A small stretch of the road passing through a town close to Shillong need to improve, Better lighting in some areas where it is too dark, like at hair pin curves and more importantly at pedestrian crossing, Free line for Bikers at toll gate, more number of parking Bays for heavy vehicles, definitely need to improve the hotels, food quality, at least at the midway; (6) The area which has only two lane road needs improvement
(7) Washroom Facility; (8) *Directions to destination*; (9) Veg Restaurants should be there, prevention from dizziness; (10) Toilets; (11) *Proper guidance to reach the destination*
(12) Pollution level from vehicles; (13) Lodging; (14) Prevention from dizziness

Based on the study, as shown in Fig. 2. Tourism Information was chosen by 53.3% which is the majority of the participants. The feedback of 14 participants is given in Table 1 here in the table also it is seen that information which is italicized is one main aspect that can have a great influence in improving the tourism industry. Giving the right information at the right time is very crucial as time is a very important factor for the tourists. Feeding information to the tourists as they are on the journey would be beneficial not only in terms of providing what they need to know but distracting them from the tiresome and tedious journey. The following guidelines have been formulated that can help frame the dimensions and concept of introducing Culture in the mini-halt stations and improve the journey of a traveler Table 2.

These guidelines can be used for devising the framework in any design area. It can be used in planning the infrastructure of the place, in service design, product design and intervention or even in graphic design. The elements proposed can be used in abstract forms to give a concrete concept of cultural tourism.

Table 2 Guidelines formulated

The Tourists are exposed to the culture as they stop for a break or for eating
The Tourists can relax their minds as they see the rituals and culture of the people. The concept of "Room with a view" will be implemented as while designing the resting places. The place should be comfortable for resting provided with a view of the culture of Meghalaya in an abstract way
Interactive avatars will be made to teach and communicate with the tourists. They will be able to teach them the gestures and the basic language
Using the symbols, Rituals and heroes discussed, the whole system will be divided according to these elements and these will be shared with the tourists

5 Conclusion

The study provides only a proposal and guideline based on some observations and ideas on the need and composition of elements identified therein. This study requires to be further extended in testing the proposed model and gathering user's and tourists' feedback. It is expected to be beneficial for promoting employment for the local people and can be taken in other different context as well. Attempts will be made to incorporate such facilities with the help of local people specifically youths and also consultations with the tourism department of Meghalaya will be done so as to meet their views and plan.

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Challenges to Sustainable Growth of the Micro-scale Kuhila Craft Industry of India

Prarthana Majumdar and Sharmistha Banerjee

Abstract The Micro and Small Scale Enterprises (MSMEs) in Handicrafts form an important part of the Indian economy. Yet, in the post liberalization era since 1991, MSMEs have fallen considerably behind the national growth rate. Besides the economic threats from opening up the economy to competing global MNCs, and the government's withdrawal of subsidies, several socio-cultural factors have also stymied the growth of these enterprises. Notable among them are the gradual westernization of culture, rural education, urban immigration and the changing gender and generational relations in artisan families. This paper focuses on one such micro scale handicraft industry in rural North East India (Assam), namely, the Kuhila craft industry and studies the challenges that this industry is facing in economic, social and cultural fronts. It also investigates the effects of environmental changes and its ability to pose as a potential threat to this industry in future.

Keywords Kuhila · Handicraft · Sustainability · Micro and small scale enterprises

1 Introduction

In a developing country like India, craft production, as an occupation, is usually taken up by the poor and marginalized hoping to achieve economic freedom through their skills. Craft production is often perceived as a *'weapon of the weak'*, an activity for those living in the fringes of the economy [1]. Since the economic

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reform of India in 1991, the government has withdrawn several protective measures for the MSMEs, exposing them to fierce competition from Large Scale Enterprises (LSEs) and decreasing their profitability [2]. As an aftermath, the growth rates of MSME units and their employment generation has dipped heavily in the post liberalization era [3]. Recognizing the economic importance of MSMEs, the government has started several training and financing programs through area Block[1] offices. However, these programs are far from wholesome. In order to be able to convert the threats of globalization and competition to opportunities, these units have to remodel their business canvasses and focus on making more market oriented products.

The vast universe of handicraft MSMEs in India at various stages of growth provides excellent natural experiments to understand the success of different business models. This paper focuses on one such micro scale handicraft industry in rural North East India, namely, the Kuhila craft industry. We investigate the challenges that this industry faces in not just the changing economy, but also in the face of the degrading environment and the tectonic shifts in the socio-cultural fabric of India. It is barely enough to associate growth with just an *economic bottom-line* today. *Sustainable growth* of a business implies greater wellbeing in four dimensions in the modern definition: *Economic*, *Environmental*, *Social* and *Cultural* [4]. Understanding the challenges that a business faces in each dimensions can aid in tackling such threats in a piecemeal manner. The micro scale of the industry also presents unique strengths and weaknesses that require careful consideration in the business model.

2 Methodology

For this study, we interviewed the small community of Kuhila craftsmen in the Nagaon district of Assam (India) through semi-structured interviews. We investigated about their business models though questions such as: 1. What are your products and who are your consumers? 2. What are your current revenue streams, costs and distribution channels? Our interviews also investigated about their raw materials, tools and production techniques. Furthermore, we probed into the socio-cultural aspects of their lives through questions pertaining to their level of education, their source of inspiration for making new products, their working hours and other activities, their desire to continue with the family trade, the role of women and children in making the crafts, use of internet and cell phones, coordination with other craftsmen in the area, etc. We also interacted with their families to understand the familial social dynamics better.

[1]Block is a sub-district level administration in India. For administrative purposes, a district administration is divided into—Taluks, blocks, panchayats and villages.

3 Observations and Discussions

3.1 The Kuhila Handicraft and the Artisan Community

The Kuhila craft, though a micro-scale cottage industry, is a famed handicraft of the Batadrava area of Nagaon district in Assam. Its heightened importance stems from its historical attachment with *Vaishnavism.*[2] Kuhila has been used for centuries for making colorful masks in mythological plays called *Bhaonas.*[3] It is also used for making prayer mats, idols, decorative artifacts and toys (Figs. 1, 2 and 3).

Kuhila is a very lightweight, inflammable material obtained from the stem of the two plants (*Aeschynomene aspera, Aeschynomene indica*) which grow in swampy areas [5]. This material, once dried, does not absorb water and is immune to fungus attacks. It has very high tensile strength along the direction of the fiber. The glue used during the process is made by boiling fiddlehead fern.

Kuhila cultivation is very similar to rice cultivation. But the manual harvesting process is more challenging since the swamps in which they grow can be several feet deep. It is harvested once a year after the rainy season. The craft material is obtained by drying the portion of the stem that was submerged in water during the growth stage, manually removing the dark colored bark and drying the pith in the sun. The dried Kuhila stems are then stored in overhead rooftop compartments.

The cultivation and harvesting is usually done by Bengali Muslim immigrants in the area whereas, the making of the crafts is done by 4–5 artisan families in the area. Historically, the trade has been confined within lineages, but of late, due to dwindling number of artisans involved in the trade, the senior most artist has trained a few other interested youths in the area. The ability to conveniently store Kuhila makes it possible for the artists to be employed all throughout the year.

Most of these crafts are sold outside temple premises and the more exquisitely designed decorative pieces are sold in exhibitions all across the country. These exhibitions are organized by the government to sustain and promote these craft industries. The state also supports them with artist's allowance and pension. Though the industry has managed to survive for centuries, its growth has been stymied by several socio-cultural and economic factors. The industry is heavily dependent on Vaishnavite patrons for the sale of its bestselling products: the mythological masks and the prayer mats.

[2]*Vaishnavism*: Major sect in Hinduism that considers Lord Vishnu as the Supreme Lord.

[3]*Bhaona:* A traditional play in Assamese, always carrying a religious message of Vaishnavism. Such plays were originally creations of Srimanta Sankardev.

Fig. 1 A kuhila craftsman slicing a sheet from the kuhila stem using a knife

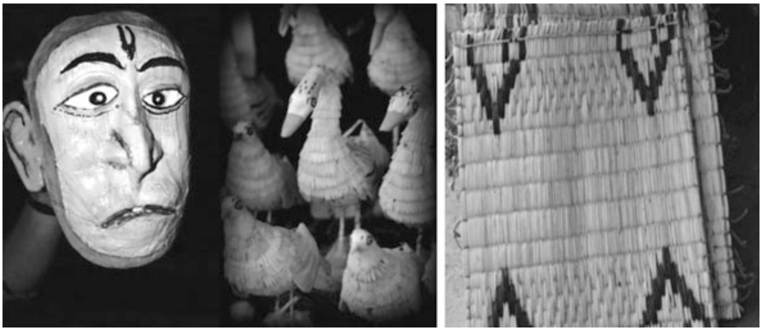

Fig. 2 A kuhila mask, crafted animals and a mat

Fig. 3 Glue made from fiddlehead fern and an overhead compartment storing kuhila stems

3.2 Economy: External and Internal Barriers

For centuries, the Kuhila craft industry has sustained as a small cluster of family businesses making products specifically aligned with the religious and cultural aspects of Vaishnavism. The craftsmen and their families have lived a marginalized existence in the periphery of an economy that has been growing rapidly for years. Several *internal* and *external* barriers can be identified as causes for lower economic growth among these families compared to the nationwide growth.

3.2.1 Internal Factors

One of the strongest causes of economic backwardness among these artisans is the lack of education. Though financial aid offered by the government is highly insufficient to stimulate growth in such industries, it is argued that the lack of education and managerial skills might be directly responsible for the inability to raise capital by these craftsmen [6]. In the present age, several Indian craft companies like Oxfam and Craftsbridge have taken to successful organic marketing on social media publicizing the stories of the maker communities [7]. The Kuhila craftsmen demonstrated no knowledge of the existence of such avenues and were unaware of sites like Pinterest and Etsy through which they could reach millions of buyers in first world countries. These entrepreneurial deficiencies cannot be traced back solely to the lack of education; the underlying disposition of the craftsmen also contributes in making them less enterprising than optimal [8]. The artisans exhibited a clear sense of pride with their art form with an undertone of resistance towards falling back completely on making commercial crafts for mass consumption. This attitude will potentially save this craft from transforming a valued craft to a mass manufactured commodity. Nevertheless, crafts need not always be commoditized in order to be commercialized. Kenya, for instance, has developed its craft industry to appeal specifically to western ethnic tastes and have frequently used '*Free Trade'* as a means of promoting their crafts in western households [9]. There is another inherent barrier to growth that is commonly faced by small family businesses. While the minimization of organization, accounting and paperwork generates internal economies, this can render it very inconvenient for the business to scale up [10}.

3.2.2 External Factors

There are several external factors that impede the growth of a micro scale and geographically isolated industry like the Kuhila craft industry. Most challenging of them is the competition that its quotidian crafts face from synthetic or other substitutes, e.g. Kuhila mats are replaced by PVC mats, Kuhila animals are replaced by plastic toys and Kuhila paper is replaced by A grade paper from bamboo. The industry has also not been able to properly channel its products to an appropriate consumer base. The external factors can be further divided under the following heads.

Lack of access to capital: The industry has few revenue streams and limited reinvestments into the business. The Government aids available are utilized for the subsistence of the artisan families and are barely enough to stimulate growth.

Lack of access to markets: The industry is located in the remote district of Nagaon in India. Besides the lack of physical proximity to the major markets in India, the industry also does not have an online presence. Most of their selling outlets are located outside the famous Vaishnavite shrines or in stalls at Government organized national level expos. These exhibitions have limited reach and do not aid in building a buying community like online campaigns do.

Long supply chains: Nagaon is located about 122 km from the nearest city, Guwahati. The inadequate transport systems of the region have led the industry to have a very long supply chain. Since the craftsmen are not organized as a cluster, they have not realized the economies of transporting in bulk and designing their products for easy transport.

3.3 Ecology: The Dwindling Wetlands

Micro and Small scale enterprises are continually faced with the external problem of living in an economy where government policies favor the LSE's in resource allocation [11]. However, the Kuhila Craft Industry, with no big competitor for raw material, is currently faced with a resource problem of another kind: depleting raw materials due to degradation of the wetlands. Anthropogenic activities like garbage dumping, residential and commercial developments, encroachment and setting up of fisheries are primarily responsible for the shrinkage of the wetlands. Most people in the district depend on these wetlands for their day to day activities like bathing, washing clothes and disposing sanitary waste. Besides the decay in the quality of the wetlands, there is a need for conservation as poaching of aquatic birds and animals have lead to an alarming decrease in flora and fauna [5]. Since the Kuhila Craft Industry is still a micro-scale industry, it has not yet been severely affected by the gradual decrease in raw materials. However, if this industry is to commercialize and scale up in future, it will find itself in a *Catch 22* situation where scaling up will need more raw materials but the over-utilization of resources will in turn limit its growth process.

3.4 The Social Fragility

The Kuhila Craft Industry comprises entirely of small family based production units run from homes. Being a household activity, the industry is structurally underpinned by generational and gender relations at home [12]. Craft industries that are run as family business are as volatile to sociological changes as they are to economic parameters. One notable risk that the Kuhila industry inherently suffers from, is the lack of diversified sources of family income which makes this trade disproportionately susceptible to market failures [13]. The lure of stable incomes through jobs in cities have already led several young members of the artisan families to leave the family trade in search of greener pastures.

The Kuhila craftsmen expressed great sense of pride for the recognition that the government gives and for the financial independence that they have gained through their art. They expressed a distinct sentiment that is commonly seen in artists, namely, '*Art over Commercialization*'. Nevertheless, it is the same sentiment that might risk losing the new members of their families who may value economic well-being more than their predecessor's sense of pride. The Government of India's 'Sarva Shiksha Abhiyan', which aims for free and compulsory education for children aged between 6–14 years, has been a *silver lining* for these artisan families [14]. The craftsmen also exhibited a sense of fulfillment with the technical training programs that the Government organized through the area Block Office. These programs, however, are far from wholesome as they focus only on skill development. The craftsmen are not educated in crucial aspects like marketing, branding, packaging, supply chain management, negotiations with suppliers and use of the internet. Providing these families with free education and no substantial support henceforth, only leaves the exit door open for this industry.

Another interesting aspect of the Kuhila craft industry is that even though it is a family trade, historically women have not taken an active part in either making the craft, growing and harvesting Kuhila or in the supply chain management. Though, if we look at craft industries across India that do employ women, their commercialization have almost always pushed the less-dominant women down the value chain to become the worker-manufacturers. The case of the famous Lucknow Chikan Embroidery industry can be taken up as an apt example. With the scaling up of the industry, most of the original skilled male embroiders went on to become middle men on the supply end. The industry started employing women to fill in the vacuum left by the male embroiders. However, the system gradually started becoming exploitative for the women employees. They had to work part time at home and earned very low wages for their work. The increasing pressure of market demand due to low prices gradually also led to deterioration in the quality of the craft [15]. Given the micro-scale of this industry and its social fragility, any future efforts to incorporate social sustainability into this industry would require careful consideration of these challenges.

3.5 The Shifting Winds of Cultural Trends

Crafts from all across India have witnessed stiff competition from foreign made goods and commodities associated with western culture. Globalization and the process of economic liberalization, opened up the Indian markets to superior technology from the developed countries and the cheap-factory made goods from developing countries. For instance, with the expiration of the Multi Fiber Agreement (MFA) in 2005, Indian markets found themselves flooded with cheap, 'fast-fashion' clothes made in

China and Bangladesh. However, the decrease in domestic popularity of Indian crafts cannot fully be attributed to the opening up of the Indian markets. The change in ethnic tastes of the consumers also finds its roots in the cultural hegemony of the West. Not long ago, Vaishnavism was a way of life for people in several districts in Assam. Today, with the trickling down of Westernization to rural India, there has been a decline in interest in the religious-cultural aspects of Vaishnavism as well as in the crafts and artefacts associated with it. The only hopeful prospect for craft industries like the Kuhila industry is to look beyond domestic consumers, redefine their value proposition and find new market niches.

The imports of artisanal products are mostly dominated by four countries currently-US, Germany, UK and France [16]. Such markets hold promising prospects for rare and exotic crafts like the Kuhila products. With the renaissance of the 'earthly' and 'natural' forms of interior décor, there has been a surge in interest in crafts from the developing countries. Kuhila artisans can heighten the sense of 'eco-friendliness' in their products to appeal to such consumers. They can also narrate the tales of their community as a marketing tool to connect to shoppers who care to read the labels on handicraft products. Crafts, in fact, serve as an excellent medium of communication between people living profoundly varied lives and the communities who make them in different countries [17]. The only caveat here is that these craftsmen, with their limited schooling and training, are unaware of such avenues.

4 Conclusion

A detailed analysis of the centuries old Kuhila craft industry revealed several economic and socio-cultural challenges and future environmental threats that this industry faces today. Along with the Government, several NGOs have extended help to such MSMEs in an effort to fuel growth in this sector. However, to ensure sustainable growth in such micro scale industries, far more comprehensive planning and implementation is required than the current level of involvement from the Government and NGOs. Besides the conventional growth strategies, any sustainable business model for this industry will require careful social and organizational design and a deep understanding of cultural trends. It is also essential to show such communities the threats arising from a rapidly changing environment. By making forest and water bodies more economically valuable to them, we indirectly sow the seeds of conservation.

5 Future Work

As future work, we plan to explore how design intervention can help this industry to make products with higher commercial value and suitable for new distribution channels. This exercise would include redesigning the current products as well as innovating new products and production techniques with the Kuhila material. We intend to work on such items as a non-slip yoga mat, window blinds, toys for babies, high-end shopping bags and stationery, shop window installations and decorative masks. We also wish to educate these craftsmen on using distribution channels such as Etsy, Pinterest and home décor showrooms. We seek inspiration from projects such as "Dutch Design meets Bamboo as a Replicable Model" that brought out new composites, surface finishes and furniture designs using bamboo [18]. We hope to contribute towards greater commercial use of eco-materials such as Kuhila and also help the craftsmen community to work together as a cluster in the production of the new products.

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InDeaTe—A Computer-Based Platform with a Systematic Design Template and a Database of Methods and Tools

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Abstract InDeaTe—Innovation Design Database and Template—is a knowledge-driven, sustainable design process support tool, aimed at improving sustainability considerations in design. It comprises a design process template that guides 'life cycle thinking' into design by creating intersections of stages of design with life cycle phases at which design activities are directed. The tool also has a design database of sustainability definitions and indicators, and methods and tools, for solving a given design problem by supporting the template. This paper discusses the potential of InDeaTe in supporting design of sustainable products, services and manufacturing systems by retaining its inherent characteristic of exploration and innovation, while offering a multitude of possibilities and routes towards achieving the design goal.

Keywords Eco-design · Sustainability · Enabling technologies and tools · InDeaTe platform

1 Methods in Design

A "methodology" is a system of methods used in an area of study, and can be a set of methods, rules, or ideas, a particular procedure, or set of procedures. It guides the design process along a route towards its goal, be it customer satisfaction,

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improvement of standard of living, or sustainable development. A common thread across methodologies is seeing design as an iterative process divided into stages, during which various activities are performed and decisions are made.

Design methods are systematic techniques to assist in developing solutions to a given design problem. According to Cross, design methods attempt to bring rational procedures into the design process [1]. Large-scale studies [5] reported that, when appropriate methods and tools were used correctly, they had significant impact on industrial practice. However, some literature also reports that design methods were occasionally used in industry [2], and that methods, when casually followed, were not very effective [3]. Only a few methods were widely and systematically used, many with ad hoc modifications, and most abandoned mid-way into the process [4]. Some of the reasons cited [4] for sparse use of design methods in practice are:

- Lack of *time* to learn new methods.
- *Incorrect* selection or use of methods leading to disappointing results.
- Use of methods based on popularity even if these did not *suit* the problem.
- Methods from written sources "unevenly" described with unrealistic examples.
- Descriptions of methods in company manuals hard to understand.
- Large number of methods available, all claiming to be generally valid.

Selection of appropriate methods is the key to their successful use [6, 7]. Various approaches are suggested to aid selection, such as multiple levels of selection [7] and method selection rules [4].

Integrated software tools, as noted in [4], aid successful use of design methods. Not surprisingly, various web-based portals and computer-based tools are developed to support use of design methods in practice, e.g. CiDaD tool [8], Landscape of Methods [9], and web-based portal 'Pinngate' [10]. In CiDaD, a model of methods is used as the representational basis, which includes process description, steps, input, output, and support for the method, along with advantages and disadvantages [8]. Strasser and Grosel [9] developed a Landscape of Methods (LoM) that uses a model of the product development process with the following stages: task clarification, concept design, embodiment design, and detail design. Further, a microcycle (situation analysis, target specification, idea generation, and evaluation) is used to solve problems at each stage. Strasser and Grosel [9] assign appropriate design methods that match the steps of the microcycle. They use a form to collect data about methods that includes name, description, purposes of the method, suitability, nature of outcome, implementation risk, and information on prerequisites, i.e. no. of people, learning effort, software needed, etc. 'Pinngate' [10] contains knowledge bases, learning/teaching environments, design methods and tools.

Further, there are several web-based tools such as EcoIt [16], SimaPro [17], and Sustainable minds [18], for supporting Eco design. However, they do not typically include methods that support synthesis activities. Methods and tools that support synthesis such as mind mapping [19], Idea-Inspire [20] are not seamlessly integrated into a single platform that would have reduced the cognitive burden of shifting across tools during design activities, potentially hindering the natural way of working of designers.

While several such frameworks are reported in literature, a major issue is the lack of empirical verification of the models used in and efficacy of the frameworks in supporting design. The work reported here builds on the learning from existing attempts and observations, in order to develop a support that is built on empirically established models and can be tested for efficacy in supporting sustainable design.

2 Research Objectives

We identify two major requirements for the use of methods in practice:

1. *Selection* of appropriate methods: *context* (design stage, activity etc.) of use of the method and expected *benefits* of using the method should be clear to the user.
2. Appropriate *Use* of the methods selected: it should be clear as to what the *costs* are, i.e. what resources and training are necessary before the methods and tools can be used; and the methods and tools should be *represented* such that it is clear as to what their start and end points are, and how to proceed from start to end.

For these requirements to be satisfied, a support is needed that: explains the structure of the methods, their key benefits and costs; specifies the context for use of methods within the design process; is easy to use and gives access to a comprehensive set of methods and tools.

A highly usable computer-based repository seems to be an option, as indicated by the recent attempts in literature. Therefore, the key objective of this research is to develop a computer-based platform on which a comprehensive set of design methods and tools can be integrated using a uniform representation of aspects such as structure, context, benefits and costs, so that these methods and tools can be identified, selected and used within a relevant context, in concurrence with sustainability as the primary motivation.

3 InDeaTe Design Tool: A Template and a Database

To fulfil the objective, a computer-based tool called InDeaTe (Innovation Design Database and Template) is developed, and tested for supporting sustainable design innovation. It has two modules: a design process *template* (Sects. 3.1 and 3.2), and a linked *database* (Sect. 3.4) with sustainability definitions, indicators, methods and tools for supporting design of sustainable systems.

The InDeaTe template is a generic representation across design processes and is distinct from any particular design process, since it does not constrain but provides direction and guidelines for the use of a number of design processes. It guides the designer by contextualizing information on definitions, indicators, methods and tools in the database so that appropriate information from the database can be used in the right context within the process followed. The InDeaTe template is based on an empirically tested, holistic framework called ACLODS, for product life-cycle development [11]. ACLODS is an integration of the dimensions of Activities, Criteria, Life-cycle phases, Outcomes, Design Stages and Structures. Built on analyses of an extensive range of design methodologies, ACLODS argues that the above dimensions are essential for developing the lifecycle of a design; it is not the design but its life cycle that impacts the environment and in turn sustainability. The InDeaTe template steers the design process through an iterative set of Activities (A) in each Design stage (D), for all Life cycle phases (L), by creating intersections for design Outcomes (O) with various aspects of sustainability as Criteria (C). The resulting design developed is the Structure (S). ACLODS provides a generic ontology for design that is used as the basis for the template and the information in the database. Note that InDeaTe is a template for a generic design process which can be governed by any criteria (and not only or necessarily sustainability); however, it is tested in this work for design of sustainable systems. The InDeaTe database currently provides a comprehensive, expandable, and editable knowledge-base of: (i) sustainability definitions and indicators that are intended to help designers clarify, for designing sustainable systems, as to "what to design for?", and (ii) design methods and tools that aid the designer in "how to design?." The database of sustainability definitions help clarify the design task at hand from the sustainability perspective, while the database of sustainability indicators prompt suitable sustainability considerations in the design.

The InDeaTe tool, which integrates the template and the database, is a knowledge-driven design process support. It is meant to be a comprehensive yet generic tool to support innovation across domains of product, manufacturing and service systems. This tool is envisioned to be a web-based, open-source support, with a growing repository of information in its database that can be used alongside the broadly encompassing process template. The tool has three main features:

(i) **Provide knowledge** of design and design processes: this is intended to be achieved using a tutorial with which to train the user in the template, database and their use. It acquaints the user with the ACLODS dimensions that are used to uniformly represent the knowledge made available, i.e., sustainability definitions and indicators, and design methods and tools, with respect to the context for appropriate use and selection of methods during design.

(ii) **Provide support** to the design process by helping users: clarify the design task with pertinent information from its sustainability definitions and indicators database, filtered using the ACLODS dimensions; and perform various design activities, considering all life cycle phases at every design stage.

(iii) **Helps create documents** that: capture the rationale of the design process with its sustainability considerations, methods and tools used, and outcomes and decisions, empowering the users to reflect on their process and to learn from the repository of design routes previously used; and also capture real-time use of methods and tools to offer feedback on its usability and usefulness, thereby providing validation of the tool.

The InDeaTe tool is intended to support design as a whole—from problem identification, solution seeking and selection, through detailing, to development of documents—i.e. elements that are critical to a professional design approach.

3.1 Description of ACLODS

Through analyses of literature and empirical studies of the design process [10], the dimensions of ACLODS (below) encompassed those used in existing design methodologies and those observed in earlier empirical studies [11, 12].

Activities are performed during the design process; the definitions of the activities used in InDeaTe are taken from the Integrated Model of designing [13], as follows:

1. Generate (G): involves bringing for the first time an outcome into a problem solving episode. Can be generating requirements (Gr), or generating solutions (Gs). Note that requirements and solutions are **Outcomes** of a design.
2. Evaluate (E): involves checking the worth of an outcome, individually or in comparison to other alternatives. Can apply to requirements (Er) or solutions (Es).
3. Modify (M): involves changing the outcome to make it better. Can be for modifying requirements (Mr) or solutions (Ms).
4. Select (S): involves selecting whether to accept or reject an outcome. This can be for selecting requirements (Sr) or solutions (Ss).

Criteria are considerations for a design. For design for sustainability, the key criterion is sustainability, which can be described using the Triple-Bottom Line (TBL), i.e. sustainability dimensions of the environment, society and economy. Examples of criteria for social sustainability might be good living condition or high level of education; that for economic sustainability might be high standard of living or high per capita income; and that for environmental sustainability might be low carbon footprint or low depletion of resources. Criteria might be represented using appropriate Indicators.

Life cycle phases of a design are the contributors to the sustainability of the system being designed. The phases consist of processes, where each process impacts the ecology, economy and society, influencing their sustainability, as follows:

1. Materials (Mat): This phase involves the processes with which the materials used in the system are made (e.g. from soil in the earth to steel for use).
2. Manufacturing (Mfg): This phase involves the processes with which the objects in the system are made (e.g. from steel to shaft/bolts and their assembly).
3. Distribution and Storage (Dist): This phase involves the processes with which the objects used in the system are transported and stored at the interface of other processes (e.g. from factory to warehouse, from warehouse to sales points, from sales points to user locations, from user locations to End of Life units, etc.).
4. Use (Use): This phase involves the processes with which the system designed is used, maintained and repaired during use e.g. installation, maintenance, etc.
5. After Use (AUse): This involves the processes with which the system is treated during the end of its life (e.g. disposal, reuse of parts, recycling of materials etc.).

Outcomes of design are either requirements or solutions. Requirements are what need to be satisfied or achieved and can be needs, demands or wishes. Solutions are as to how the requirements could be fulfilled, at different levels of abstraction from concept to embodiment. These outcomes emerge and co-evolve through the stages of design. Outcomes are in turn impressed upon by the criteria. For example, the 'low Environmental Impact' criterion may give rise to the solution-outcome 'use of recyclable material' or the requirement-outcome 'reduce carbon footprint', which in turn may lead to the solution-outcome 're-use of component'. Thus, it is important that the requirements be clarified and outcomes vetted frequently during the design process.

Design stages are four broad temporal divisions within the design process, as prescribed in most design methodologies. Each stage has well-defined deliverables that act as input for the next stage. Outcomes, as requirements or solutions, emerge and evolve during these stages, at various levels of abstraction. However, ***in reality, design is not a linear process***; the starts and ends of design stages overlap. The designer is encouraged to move fluidly among stages, with the overall intent to move forward.

Structure of a design are the entities that the designer conceptualizes and embodies during the design process. In products and manufacturing systems, structure is often recognized, typically at the embodiment stage, as physical objects: sub-assemblies, parts, features and their relationships. Empirical studies further reveal that an abstract structure exists even at the conceptual stage. Service systems may appear intangible as a whole, but can still be detailed for implementation and tested for effectiveness.

3.2 InDeaTe Template

The InDeaTe platform supports the designer to define the design system using various criteria e.g. functionality, cost and sustainability. The InDeaTe template provides a generic overview of the design process, see Fig. 1. It represents the junctures of problem-finding and solution-seeking as explicit intersections of the dimensions of *stage*, *activity* and *lifecycle* phase of the design. The other three dimensions of ACLODS are implicit. At any of these intersections, one explores *outcomes* against various *criteria*, within various levels of the *structure* of the system being designed.

The Template explains the **Design Stages**—*Task Clarification, Conceptual Design, Embodiment Design and Detail Design*; and **Life cycle phases** of the system designed—*Materials, Manufacturing, Distribution and Storage, Use and After-use*. It promotes lifecycle thinking for improving sustainability by encouraging exploration of design outcomes across lifecycle phases that are contextualized within the design process. The template guides the designer to perform iterative **Activities** of design, i.e., *Generate, Evaluate, Modify, Select*; at each design stage considering all **Lifecycle** phases, from material to after-use; this is represented as intersections. Activities are performed keeping in mind the **Criteria,** and **Outcomes** emerge as requirements or solutions. Solution-outcomes evolve into conceptual (solution)-**structures** and finally Embodiment Structures before resulting into a complete and detailed design.

Exploration at each stage is supported by information from the database. Sustainability definitions linked to indicators act as criteria to drive formation of requirements. The database supports design by providing methods applicable for

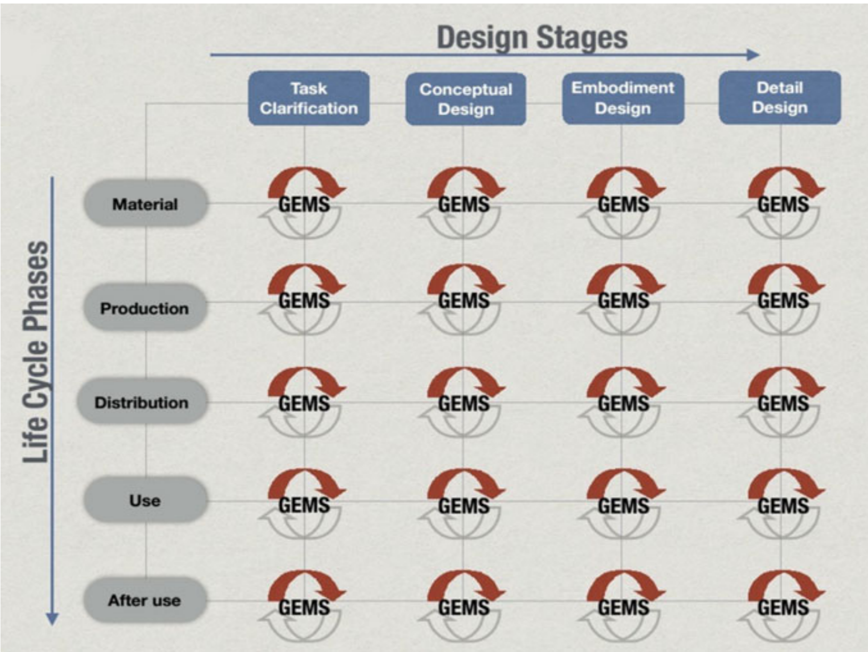

Fig. 1 The InDeaTe design process template

use at each intersection. The process focuses on the whole lifecycle of the system designed, to improve e.g. 3 pillars of sustainability where impact is significant and change is feasible.

3.3 Steps of the InDeaTe Design Process

The steps recommended to be followed during the design process are as follows:

Task Clarification (TC): *During this process, a well-defined list of requirements should be formulated. Ideas for solving the problem may arise and are to be noted down for further use, but solving the problem should not begin.*

1. Select System Boundary: Analyze the problem brief to ask these questions: What is allowed to be changed? What is not allowed?
2. Analyze current situation to identify issues (*Generate Requirement*): What are the current systems in this area? What are their life cycles? Where in these life cycles are major issues (sustainability and otherwise)? Materials? Manufacturing? Etc.
3. Using the tool/database to select Sustainability Definitions and Indicators to be used in the process: What is the guiding definition of sustainability used in this work? What are the guiding principles being followed? What are the indicators that would be used to operationalize these?
4. Evaluate the issues to find the important ones to address (*Evaluate/Modify Requirements*): How important is each issue? Can the issue be refined? What requirements can be used to represent each issue? (*Generate Requirement*)
5. Decide on a list of requirements and their relative importance for use the subsequent stages (*Select Requirement*): What requirements are really important to keep? How important are these relative to one another? Can these be quantified?

Deliverables from TC:

- A (qualitative) list of requirements, some indication of their relative importance;
- Some ideas of how to solve the design problem, noted down for further use.

Steps in Conceptual Design (CD): *During this process requirements will become more refined, more specific to individual sub-systems or parts, and more quantified. Use these to refine the list of requirements and importance.*

6. Generate alternative ideas to satisfy each major requirement (*Generate Solution*): How to satisfy this requirement? What are the other ways it can be satisfied?
7. Evaluate these ideas to select the most promising ones (*Evaluate/Modify Solution*): which of these ideas are feasible? Which ones will have a greater effect?

8. Integrate these ideas to generate alternative solution principles (*Generate/Modify Solution*): What possible combinations of these ideas can be complete solutions to the problem? Are there additional elements needed to put these together?
9. Evaluate these alternatives to select the most promising solution principle (*Evaluate/Select Solution*): Which of the combinations best satisfy the requirements? Which of these is the most feasible?

Deliverables from CD:

- A more concrete list of requirements;
- A list of alternative solution-principles that could satisfy the requirements;
- An evaluation of these principles for their ability to satisfy the requirements;
- The solution-principle selected as the most promising for further development.

Steps in Embodiment Design (ED): *During this process, requirements will become even more refined, more specific to individual sub-systems or parts, and even more quantified. Use these to refine the list of requirements and importance.*

10. Develop alternative, concrete configurations of the sub-systems/parts for the solution principle chosen in CD (*Generate Solution*): How can each subsystem of the solution principle be embodied? What are the other ways it can be embodied?
11. Evaluate and select among these alternatives based on their suitability (*Evaluate/Select Solution*): Will the alternatives satisfy the (refined list of) requirements?
    Can these be tested via calculation, virtual simulation or physical simulation?
12. Integrate these to generate alternative solution-embodiments (*Generate/Modify Solution*): Which embodiments of these concepts can be developed into complete configurations? Are additional elements needed to put these together?
13. Evaluate these alternatives to select the most promising solution-embodiment (*Evaluate/Select Solution*): Which of the combinations best satisfy the requirements? Which of these is the most feasible?

Deliverables from ED:

- A more concrete list of requirements;
- Alternative, feasible configurations for use to embody the solution principle;
- An evaluation of these configurations for their ability to satisfy the requirements;
- The configuration selected as the most promising for further development.

Detail Design (DD) stage typically requires a large amount of domain-specific information, and therefore is left out from this generic recommendation.

3.4 The InDeaTe Database

The database is organized in an easy-to-use structure. It aims to provide a holistic overview of design routes that could be charted by using methods and tools for selected sustainability definitions and indicators representing the problem. The database is classified using the type of design and domains. It allows exchange of information between the *design task* and the *design process*. These two elements: task and process are supported respectively by the 'definition and indicator' database, and 'methods and tools' database. InDeaTe not only enables creation of new routes but also aids in following established routes, e.g. those proposed by certain design methodologies.

3.5 What to Design For?

There are many definitions of sustainability, for varied contexts, dimensions and domains. Also, there are various indicators of sustainability; work is in progress to connect these two. Using indicators for a given definition, the designer specifies the intent of the design to be sustainable. The definition and indicators database in InDeaTe supports specification of sustainability requirements for a design problem. Each definition and indicator is categorized by TBL and ACLODS [12].

3.6 How to Design: Analysis of Design Methods to Support Design

To reiterate, a design process begins with task clarification for the design problem, moves to solution seeking at the conceptual stage, and solution refinement at the embodiment and detailed stages. Methods available in the database for each stage of the design process, and the know-how for using these, aid the designer. The Design Methods database in InDeaTe platform is based on a simple, input-steps-output representation along with its structure, benefits and requirements. Further, each method is linked to case studies on where and how it was used, with its benefits and costs.

The design process is realized by using the methods and tools, upon selection and supports a variety of tasks, e.g. ideation and evaluation, at various design stages, for various lifecycle phases. The listing of appropriate design methods and their selection for a particular design activity in a particular design stage is enabled by the following:

(1) Each method or tool is categorized using ACLODS: For e.g., Brain storming method is tagged with generation (activity) of requirements and solutions

particularly in task clarification and conceptual design stages, with generic TBL scope, for all life cycle phases.

(2) Each method and tool is described to help understand its objective, inputs, steps, outcomes, benefits and costs; so as to align it with the objectives of appropriate use and selection for a given context.

4 Case Studies

Six case studies were conducted so far to test the efficacy of the InDeaTe tool. Each study is on one of the 3 types of problems: product, service or manufacturing system, in two countries, India and the USA, by mixed student teams, to improve existing solutions to real problems, with and without InDeaTe and were compared. The observations were the following: (1) In the 4 cases in which problems were solved without InDeaTe, methods were used only 6 times. Designers followed their own processes using collective knowledge; (2) In CS2, although designers used some methods, participants from non-design backgrounds had to struggle to apply these methods; (3) In the 6 cases that used InDeaTe, methods were used 26 times. Each case study has been discussed in detail as papers [21–26].

5 Discussion

Landscape of methods by Strasser and Grosel [9] has a general product development process along with a microcycle of activities; they have a situation questionnaire to help designers select methods. The InDeaTe database structures methods using the four stages prescribed by [17]. Similar to the use of micro cycle in [9], InDeaTe follows the GEMS cycle [13]. Lindemann [14, 15] developed CiDaD, a web-based portal and tool, using a model of methods [8]. The design methods database in InDeaTe is based on a simple, input-steps-output representation along with its structure, benefits and requirements, as proposed in literature [14, 15]. Further, each method is linked to case studies on where and how it was used, with associated benefits and costs. However, none of these tools [CiDaD, Landscape of Methods] considered the life cycle phases of the product within the design stages that assigns methods for sustainable design, nor did they include empirical testing. These are the novel aspects of the InDeaTe tool. The database is reasonably comprehensive (36 sustainability definitions, 379 sustainability indicators, and 158 methods). We argue that keeping as many tools and methods as possible is important, since it gives a wider set of options to choose from.

6 Summary, Conclusions and Future Work

Although design methods can have significant impact on designing [5], there is skepticism towards their use in industry. This grew out of two key requirements: selection of appropriate methods for the design context, and appropriate use of the methods selected.

To address these, with sustainability as the focus, a computer-based tool InDeaTe is developed; it uses a design template made of design stages, life cycle phases and their intersections with GEMS activities. The template is based on the empirically validated ACLODS framework. The tool has a database that contains: sustainability definitions, sustainability indicators, and design methods and tools. The methods have been represented with information similar to those from literature.

The InDeaTe tool has been tested with six case studies [21–26]. It was found that, though methods were used, in cases that did not use the InDeaTe tool, the frequency of use was far less than when InDeaTe was used. Further, participants in the studies felt that use of InDeaTe helped them carry out design with better focus on sustainability.

More case studies, however, need to be conducted to assess its benefits conclusively. Eventually the tool should be made capable of empirically capturing the methods used more often or found to be efficient from the feedback received, and in turn support quick and easy selection of appropriate methods.

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Application of InDeaTe Design Tool for Designing Sustainable Products—Case Study of a Natural Water Cooler

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Abstract InDeaTe is a design tool developed to support designers to innovate using a methodical process. It has a process template and a linked database of methods. This paper discusses the application of InDeaTe tool for redesigning a natural water cooler developed by a grassroots innovator in Gujarat in order to make it more sustainable and successful in the market. Two design teams were involved in solving the problem at hand: one used the tool; the other did not. The outcomes of the design activities were compared. Analysis of the design documents and recordings showed that the team using the tool covered more aspects of the design and hence generated better design compared to that the team without the tool. This study indicated that InDeaTe toolbox could help in developing better design outcomes for product design problems. Future work on InDeaTe includes expanding its database and improving its usability.

Keywords Eco-design · Design for sustainability · Enabling tools · InDeaTe tool · Product design · Life cycle phases · Stages of design · Design methods

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1 Introduction

In hot and dry climate, people seek cool water for drinking. The drinking water coolers installed at public places need electricity and regular maintenance for sustaining the service. To address these problems, Mr. Arvind Patel, a grassroots innovator in the Indian state of Gujarat, who has been documented by National Innovation Foundation (NIF), Ahmedabad, developed a natural water cooler (NWC) which works on the principle of evaporation and does not need electricity. It is claimed to have low maintenance cost and is hence deemed suitable for public places and at places without electrical power supply.

This case study describes a re-design of the natural water cooler in order to improve its performance and appeal and to make it more sustainable. An experiment performed on students shows the difference that the use of InDeaTe tool brings in designing of a product. The resultant design is evaluated against a design generated without using the tool, to assess the improvement in sustainability considerations with the use of Tool.

2 Design Exercise

2.1 Exercise Summary

The design exercise was undertaken in June 2015 at the Centre for Product Design and Manufacturing (CPDM), Indian Institute of Science (IISc), Bengaluru. The design problem was introduced by a representative from National Innovation Foundation (NIF), Ahmedabad. The exercise was conducted in two sessions with a separate team in each one using the tool and the other without. The design outcomes were presented and feedback was taken from NIF. The design outcomes were primarily analysed for improvement in sustainability of the system.

2.2 Exercise Duration

The exercise was approximately for 16 h, spread over two consecutive days:

Day 1—Introduction to Problem and Task Clarification;

Day 2—Conceptual Design and Embodiment Design.

2.3 Design Teams

There were two teams:

Team 1 without the tool comprised of two PhD and one Undergraduate (UG) student.

One was a senior PhD Student from IISc, working on Design for sustainability, with Bachelors in Mechanical Engineering and Masters in Product Design, with Sustainability as the PhD topic.

The senior PhD Student from UC Berkeley was working on Hydrogen fuel cells, with background in Mechanical Engineering.

The UG student was pursuing B.Tech in Production Engineering from IIT Roorkee India.

Team 2 using the tool comprised of three PhD students and one UG student.

One was a junior PhD Student from IISc, working in the area of Network-enabled Manufacturing, with background in Mechanical and Biomedical Engineering.

One was a junior PhD Student, from IIM Ahmedabad, working in the area of Water-Energy nexus for sustainability, with background in Environmental Engineering.

The third was a junior PhD Student from WSU, working in the area of Life Cycle Assessment (LCA), with background in Mechanical and Civil Engineering.

The UG student was pursuing B.Tech in Mechanical Engineering from IIT Ropar, India.

3 InDeaTe Tool

There are various kinds of design support that focus on sustainability; however, most of these are for assessment and evaluation, such as the Swiss Ecoscarcity methods (Ecopoints) [1]. Certain tools such as DFE Workbench [2] are well-integrated with Solidworks CAD tools, and are able to support designers with respect to specific aspects of a design, environmental aspects in this case. There are other design methods that support only a specific phase of the Life Cycle e.g. the Use-phase [3].

Interaction of methods and tools at the various steps in the process of design has been noted in literature, and the need for interaction between design methods and computer-aided tools to support decision-making has been stressed [4]. Lopez-Mesa [5] enumerated potent findings about the knowledge and use of design methods in practice; she highlighted that very few methods are widely and systematically used, while most people are not aware of the availability of other methods, or believe that a large amount of time is required to use these methods. However, she notes that application of methods supports an array of tasks during the design process and leads to consideration of a large number of ideas.

Lopez-Mesa further stresses that a method contributes better to the design when it is within a computer based system [5]. Thus, there is need for computer-based support that covers all three pillars of sustainability—environment, society and economy—across the entire life cycle of the object of design, and addresses the need for improving sustainability of existing systems, with the systematic integration, to practice, of methods and tools.

The InDeaTe Tool [6] is a knowledge-driven support for designing sustainable products, services and manufacturing systems. It comprises a design process template and a database that work together to support designers through a computer interface. The template is developed from the ACLODS framework [7] as the basis, which presents a new paradigm of design in terms of the dimensions of Activities, Criteria, Lifecycle (LC) phase, Outcomes, Design Stage and Structure. The tool introduces the user explicitly to some of these dimensions, viz. Activities, LC phase and Design Stage, before prescribing the Template. The template offers an overview of the design process and provides a generic guideline to follow during the process. Four stages of design have been prescribed Task Clarification, Conceptual Design, Embodiment Design and Detail Design [8]. Every design has up to five Life cycle phases: Material extraction, Production, Distribution, Use and After Use. The Template encourages designing for the entire LC of the product, with the aim of making it more sustainable. At any point in the design process, designers perform one of these four activities Generate, Evaluate, Modify, and Select; abbreviated as GEMS.

The database consists of sustainability definitions, sustainability indicators and design methods, tools and principles. The definitions are meant to help clarify the design task at hand with respect to the sustainability perspective adopted, while the corresponding indicators prompt the relevant sustainability considerations in the design. The methods are intended to aid the designer in the design process to achieve these sustainability considerations. The tool is a platform where the template is introduced and the details of the design exercise, such as problem brief and details of participants, etc. are collected into a document for future reference. Before starting the design exercise, the user selects the type of design; the InDeaTe tool currently supports design of products, manufacturing systems and service systems.

4 Solution Without Tool

The team without the template first identified the requirements as follows:

- Provide affordability/reduced cost
- Provide accessibility for increased number of users in public (e.g. different heights)
- Provide service entrepreneurship (should provide more employment)
- Reduce weight: ease of packaging and distribution

- Increase indoor use (may affect humidity, space, fungal growth, capacity change)
- Making it multi-functional (e.g. heating up water in winter)
- Arrive at one standardized requirement for cylinder volume
- Decrease water cooling time to serve more people
- Separate containers to avoid loss of cooling
- Reduce size of the whole NWC.

Then they classified the parts of the device as either standard (parts bought off the shelf) or manufactured (non-standard parts specific to the design), as follows.

Manufactured parts: SS tank (Cost: bending, welding, cutting, Grade of steel = SS304), SS sheets, SS frame, Mounts (bending and welding).
Standard parts: Solar panel, viscose around copper tube (bending), bending viscose copper tube, fan assembly, purifier assembly, tap assembly, dripper assembly, and final assembly.
A framework of solutions for manufactured parts was created, wherein the requirements were matched with the manufactured parts. Manufacturing techniques were assessed for their ability to satisfy the requirements and proposed solutions were noted in the corresponding cells. Finally, the team came up with conceptual sketches (Fig. 1) and a new bill of materials (Table 1) showing major cost reduction.

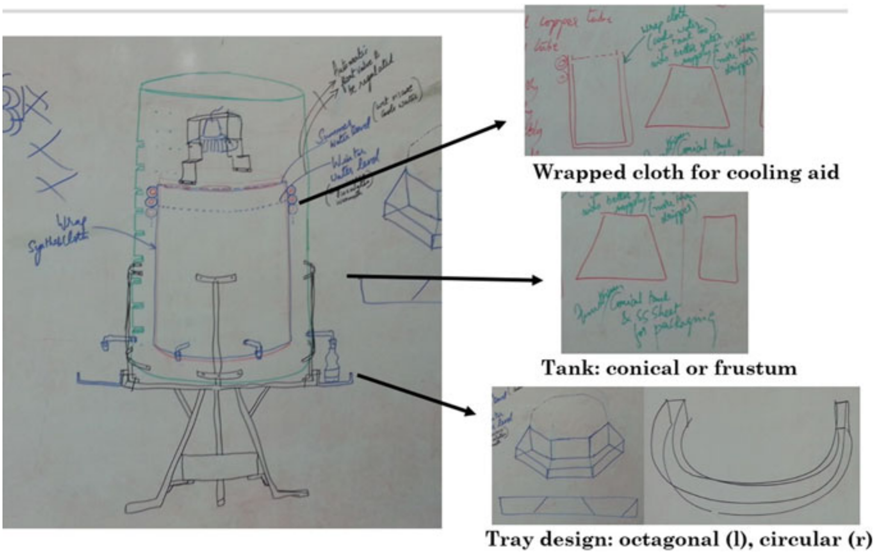

Fig. 1 Sketches of new design of natural water cooler without using InDeaTe tool

Table 1 Bill of materials of the new design created using the tool

	Component		No. of Units			Weight (kg)			Unit cost (₹)			Cost (₹)			Labour cost (₹)			Total cost (₹)		
	O	New	O	A	B	O	A	B	O	A	B	O	A	B	O	A	B	O	A	B
Manufactured parts	Structure including stand (SS304)		1			13	8	13	240/kg			3120	1920	3120	2500	1540	2500	5620	3460	5620
	SS sides of outer body (SS304)		4	1	4	25	22	25	240/kg			6000	5280	6000	1800	1000	1800	7800	6280	7800
	Tray (SS304)		3	1	3	6	18	6	240/kg			1440						1440	1440	1440
	Cylindrical stand (SS304)		1			3			240/kg			720						720	720	720
	Cylindrical tank (SS304)		1			10			240/kg			2400			400			2800	2800	2800
	Tray for drained out water		1									250						250	250	250
Standard parts	Wrapped cloth		0	1	0	0	0.5	0	0	200/kg	0	0	100	0				0	100	0
	Copper coil	Bundy coil				10.5			630/kg	100/kg		6615	1050	1050	300			6915	1350	1350
	Automatic float chamber											300	150	300				300	150	300
	Taps		6	8	6				100/unit			600	800	600				600	800	600
	Nuts/bolts					0.5			500/kg			250						250	250	250
	Plumbing material											1200						1200	1200	1200
	Purifier		1	1	2				700			700	700	1400				700	700	1400
	Miscellaneous											2000						2000	2000	2000
	Viscose cloth					10			150/kg			1500						1500	1500	1500
	Accessories (SS304)					1			240/kg			240						240	240	240
	Solar panel		1									2000						2000	2000	2000
	Blower (12 V DC)		1									900						900	900	900
																		35,235	26,140	30,370

O = original design, A = without tool, B = using tool

5 Solution with Tool

In the Task Clarification stage, the team using the template identified the system boundary, selected the indicators and analysed the current situation. They identified the requirements as per the life cycle phases, generated ideas accordingly in the Conceptual Design stage by brainstorming, and developed solution variants. In the Embodiment stage, the selected concept was evaluated using Fault Tree Analysis. The 6R principle was followed throughout. In the final solution, some modifications were recommended outright, while some were suggested after more detailed analysis.

5.1 *Task Clarification*

The system boundary was set as follows: The cooling capability of the device should not be compromised, and cost should not increase significantly. The filtration type, energy source, size, materials, and layout can all be changed.

Issues with the current situation were identified as the following:

- Cost is as high as conventional devices in the market
- Filtration and cleanliness of the device must be taken care of by regular maintenance
- It is not easily portable
- Due to modest aesthetics it is perceived as a cheap substitute to conventional devices, which affects its social acceptance to some extent.

The requirements were identified and classified as demands or wishes, as follows:

Demands: cooling, filtration, independent of external power source.
Wishes: inexpensive, durable, low maintenance, aesthetic, portable.
The Problem Statement was stated as the following: Improve the design of the natural water cooler to make it more cost effective over its lifecycle and appealing to users while performing all the necessary functions.

5.2 *Conceptual Design*

For each major requirement, ideas were generated using brainstorming. Some of these ideas were shortlisted for their relevance and feasibility. The requirements were also classified according to the phases of the lifecycle. During this exercise, some new requirements were also identified, though these were not high on priority. The shortlisted ideas were enlisted along with ideas for the newly identified requirements.

5.3 Embodiment Design

The configuration of the device was determined after the conceptual design stage. In order to make the device more reliable, the proposed design was subjected to a Fault Tree Analysis (FTA). Following the FTA, a final set of recommendations was proposed to design the device.

- Change tubing material from copper to Bundy tube (copper coated steel)
- Move filter from bottom of tank to top of tank
- Use automatic shut-off filter to ensure that water is always clean
- To facilitate automatic shut-off without cutting off water supply use a two filter system with a valve to switch to the other filter when one becomes inoperable
- Move blower from top of device to the bottom to create a more efficient counter-flow heat exchange
- Use spring-loaded taps to reduce water waste from people leaving the tap on
- Recycle drain water to use for evaporation water by way of a sieve and a small solar panel driven pump to reduce water wastage
- Change the shape of the tube (e.g. square cross section) to increase surface area from which to achieve cooling
- LED display light to signal when filter needs change.

Based on these recommendations, the layout of the new design was developed and was compared with that of the old design (Fig. 2).

On the basis of the selected design and configuration, a preliminary cost analysis was done to check whether any cost reduction was achieved (Table 1).

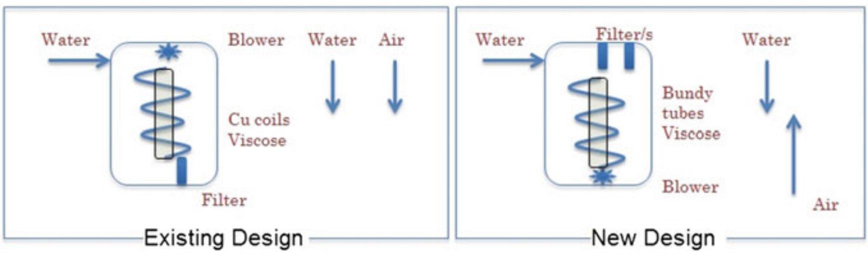

Fig. 2 Schematic diagrams of old and new designs using InDeaTe tool

6 Analysis of Design Processes

The control variables in this study include an engineer/designer, the given problem, template and the database, whereas the discrete, uncontrolled variables consist of the engineer/designers' educational background and prior experience, individual and group dynamics, in addition to expert intervention. Although the team using the tool did not explicitly select any definition of sustainability, it followed the triple bottom line [9] and 6R principles throughout the design process. The team using the tool found it difficult to choose and apply indicators from the database, as these seemed to be too generic for this purpose. Though both teams generated a list of requirements initially, the team without the tool focused mostly on the manufacturing phase of the device. On the other hand, the process followed by the team using the tool was more structured and covered all phases of the life-cycle. Considering the time constraints of the exercise, they chose simpler methods. The choice of methods was also influenced by the participants' prior experience. The team without the tool generated an innovative design with respect to the manufacturing process and cost, but the team using the tool also covered various other considerations in their design. So, the tool seems to provide an edge to the team by aiding to be comprehensive in providing an efficient and effective, sustainable solution by considering all design and LC stages.

The limitation to the experiment is the potential lack of parity in groups with respect to the participants' education and prior experience. It is possible that a participant, who is already a good designer, or has prior knowledge of sustainability, life cycle analysis and/or cost/benefit analysis or any other relevant skill, will bias the experiment. However, the attempt of this experiment is to provide more options, a structure, and considering all aspects of designing and lifecycle stages, in addition to an engineer/designers' prior experience. The study clearly shows that an attempt to provide a more sustainable design in a short period of time with the help of InDeaTe tool is possible. When this exercise was conducted, the tool was in a primitive state. Therefore, the process of using the database was not very clear, and the categorisation of methods was not very convenient. These issues have subsequently been addressed in the later versions of the tool. The team using the tool also felt that following a rigid structure in the given time frame inhibited them from pursuing unconventional ideas. More time during the brainstorming session, and the awareness about the tool to aid at being comprehensive at the design stage and not just as a checklist of tasks, may help. Moreover, the database at that point seemed to lack in methods for certain purposes, e.g. social (human behavioral) systems. Lastly, other factors could have influenced the design processes in both the teams, like group dynamics. These factors also play an important role and impact the groups output to some degree.

7 Conclusions

The participants felt that although the InDeaTe tool provided a structure to the design process, it should not be inhibitive to the designers. The database needs to be populated so as to address a comprehensive set of possible scenarios during the design process. Some of the learnings from the study include addition of the typical duration of time needed to use the tool, and the software skills required to use the database. Future work involves applying the tool on a wider variety of design problems so as to understand the major areas of strengths and weaknesses, so that appropriate modifications could be initiated.

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A Methodological Basis to Assess and Compare Manufacturing Processes for Design Decisions

Manish Kumar and Monto Mani

Abstract Any product or artifact, once designed, realized and adopted by users, has a complex bearing on the environment, energy and society, depending on its various life-cycle phases. Depending on the product, this bearing could be embodied or active, and can be traced socio temporally over diverse geographies. Embodied bearings essentially include impacts (environmental, energy, societal) that have ensued in the realization of the product, while active bearings include ongoing impacts in its use and disposal. For e.g. the manufacture of plastic bottles involves extensive dependence on fossil fuels, water and carcinogenic additives, while in its use phase it could be responsible for significant societal impact across various geographies by leaching hormone altering chemicals such as BPA. The former impact is embodied while the latter is active. Environmentally sensitive designers generally remain focused on the choice of the material integrated in the product, but remain clueless on the actual manufacturing processes involved. While a designer makes the best choice of material keeping in mind environmental performance, manufacturers abide by material performance specifications and are generally at liberty to choose the manufacturing process that is most economical. The decision on the type of process to use depends on the cost, region, energy and resources involved, influenced by regional environmental regulations. While, a lot of studies suggest improvements in environmental impacts at various levels (process, systems, factory, multi factory and global supply chains level), there are barely any studies on an integrated assessment to compare various manufacturing process. The current paper provides a methodological basis to assess and compare manufacturing processes, for the same product/material specification, to aid

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environmentally sensitive decisions. Such studies would bridge the gap between designers and manufacturers.

Keywords Product life cycle assessment · Design decisions · Manufacturing environmental impacts

1 Introduction

In last few decades, due to increased environmental concerns, inclination of manufacturing enterprises towards assessing impacts of their activities has increased, primarily attributed to imminent sustainability concerns. A number of methodologies have been developed to assess impacts of various products, processes and systems using different approaches [1], the approach differ in their scope of assessment within a product lifecycle and/or the boundary of manufacturing setup. The impacts may be embodied or active depending on the phase of the life cycle. Embodied impacts are caused due to the processes involved during the realization of a product and impacts associated would broadly include energy, water, environmental, resources etc.; while active impacts are caused during the use phase of product e.g. BPA, which is one of the widely used chemical in manufacturing of beverage cans, plastics, dental sealants etc. has adverse effects on human health. Wong et al. [2] has discussed in detail the potential health impacts of BPA in China and on human health. There are studies on adverse effects of various other chemicals too including PBDE's used in many appliances and fabrics, phthalates used in cosmetics, PFA's used in furniture fabric and non-sticky pans, lead paints used in toys etc. [3]; are all active impacts. Such impacts rarely surface in prevalent LCA methodologies as they are difficult to monitor and quantify precisely. This is due to the fact that the diffusion of the associated product across socio temporal geographies is difficult to trace. Socio-temporal implies the societal implications (health, behavior, benefit, etc.) associated with the adoption of a product over time traced across various regions. While studies have clearly indicated that methodologies adopted till now are based on poor scientific grounds [4], this can be attributed to the fact that (i) ground realities vary, (ii) user adoption in most cases is unpredictable and (iii) difficulty in monitoring and quantification. Designers are generally concerned about the material choices for the products, but choice of actual manufacturing process involved is not really looked upon. The designers indicate design and production requirements, but do not indicate processing requirements [5]. Decisions on manufacturing are primarily economy driven, which are influenced by cost of processing, energy use and environmental impacts associated to some extent. Figure 1 shows a schematic representation of product life cycle and stakeholders involved.

Most of widely used assessment methods attempt to assess embodied impacts at process, systems or supply chain level, but hardly any method focuses on active impacts in detail. In a globally distributed manufacturing and distribution network,

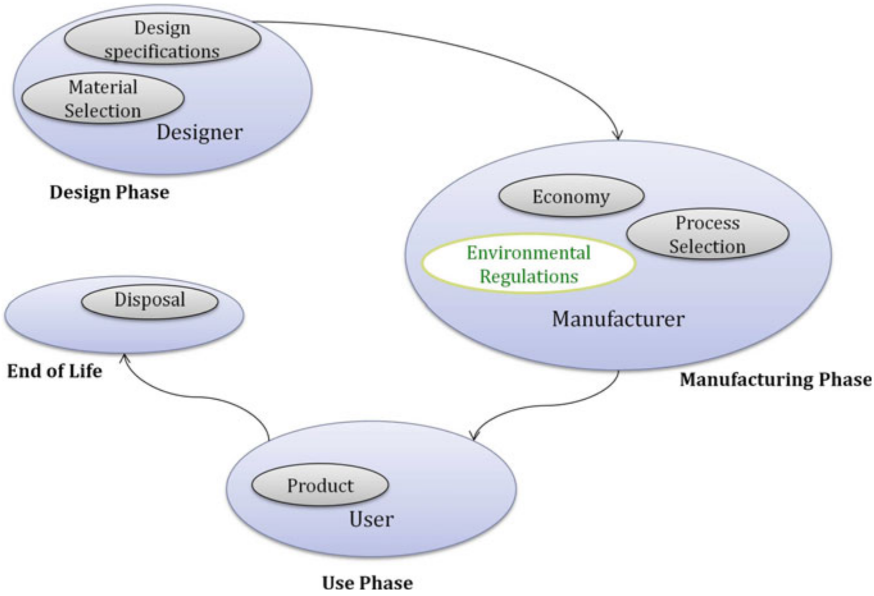

Fig. 1 Schematic representation of phases of product life cycle and stakeholders involved

it is even more difficult to precisely monitor and quantify the active impacts, given the specific regional diversity and usage patterns e.g. it is common in developing countries to use plastic bottles to carry hot beverages like tea, while in developed countries these are used to refrigerate fruit-juices and water. The active impacts in both are not the same. Ideally, a life cycle assessment method should comprehensively assess impacts (embodied and active) of a product during all its life cycles in an integrated manner. LCA, today, comprises of life cycle phases that are networked and distributed globally [6]. Recognizing and tracing this network is a crucial challenge, given the fact that consequences of extraction, manufacturing, use and disposal phases attributed to a product are not equitably distributed in the network. The material extracted at one location is processed, used and disposed at another. Life cycle assessment must thus attempt to discern this global distribution of related location specific consequences [7]. To summarize, it can be stated that there is requirement of a methodology to compare and assess manufacturing processes for impacts they cause in all phases of a product life cycle. Resulting information will help designers and manufactures to estimate impacts of products and take better decisions regarding the material and possible manufacturing process selection during design phase.

The objective of this paper is to study the effectiveness of product assessment methods in addressing impacts (embodied and active) associated with a product during its life cycle and propose a methodological basis for comparison of manufacturing processes for design decisions. To meet the objective, existing approaches have been reviewed and compared based on the challenges in “development of measurement science for sustainable manufacturing" as identified by Mani et al. [4]. Finally, the paper concludes with future directions towards developing a methodological basis to compare manufacturing processes for design decisions. The remainder of this paper is structured as follows: In Sect. 2, existing product life cycle methodologies are discussed in detail. In Sect. 3, methodologies discussed in Sect. 2 are compared against the challenges in developing measurement science for sustainable manufacturing. Section 4 concludes with the discussions and current understanding regarding the limitations of existing product life cycle assessment methods and future directions for development of such method.

2 Background Review

Several methods are available which attempt to assess the impacts of products. A comprehensive study of sustainability assessment tools has been done by Ness et al. [8]. The study classifies available sustainability assessment tools into three categories (Indicators, product related assessment tools and integrated assessment tools) based on their prime focus and concludes that most of the available tools focus more on environmental, social or economic impacts individually [8]. Few methods have integrated approaches towards all aspects by combining nature society dimensions, but they are not commonly used [8]. This section briefly discusses four product life cycle assessment methods, which are more applicable to manufacturing; Life cycle analysis (LCA), Unit process life cycle inventory (UPLCI)—CO_2PE! initiative (cooperative effort on process emissions in manufacturing), Thermodynamics approach and Sustainability characterization methodology. Each approach is briefly described and reviewed in following subsections.

2.1 Life Cycle Analysis (LCA)

Life cycle analysis (LCA) is one widely used product life cycle assessment method comprising of life cycle phases; material extraction, manufacturing, production, use, reuse and disposal. "Life cycle assessment is a "cradle-to-grave" approach for assessment of impacts of manufacturing systems" [9].

LCA approach consists of four steps: Goal and scope definition, inventory analysis, Impact assessment and Interpretation [10]. Life cycle costing (LCC) and Social life cycle assessment (SLCA) have further evolved for assessment of impacts in economic and social dimensions. LCC approach has evolved from cost assessment point of view. It takes into account various types of costs (operational, direct, indirect, internal, savings, hidden etc.) associated with a product during its entire lifecycle [11]. Some LCC tools also address environmental impacts to some extent. A detailed list of available LCC tools is presented by Gluch and Baumann [11]. On other hand SLCA focuses on social impacts by following the steps of traditional

LCA method. Impact and stakeholder categories have been identified for stakeholders and social dimensions [12].

Despite the broad application in practice, limitations and drawbacks of LCA are reported in literature. Conducting an LCA is time and resource consuming [4, 9, 13]. Collection and availability of data is another issue which may affect the correctness of results [9]. Also, Lifecycle Inventory (LCI) database used by most of LCA softwares uses generalized data for assessment often limiting their scientific validity. On the other hand, Input-Output databases uses process level aggregated data rather than individual product level [14]. "The information is region specific, the scientific validity of the LCI data is not known as assumptions are not well documented" [4]. LCA focuses at providing a complete view of environmental impacts. Finnveden et al. [13] concluded that all types of impacts are not well addressed in LCA. Also use phase of a product has received little attention [15], which primarily falls under active impacts.

2.2 Unit Process Life Cycle Inventory (UPLCI)—CO_2PE! Initiative (Cooperative Effort on Process Emissions in Manufacturing)

Keeping in mind the limitations of LCA, efforts have been made by Kellens et al. [14] within CO_2PE! initiative to provide reliable and quality unit process data for life-cycle inventory (LCI) databases. The drawbacks of LCI databases are clearly indicated in this study e.g. incomplete data on manufacturing processes and emissions, available data for limited (only conventional) manufacturing processes etc. In addition to this, input/output databases have data based on groups of processes i.e. aggregated data for number of processes. The goal of this method is to provide reliable data, fulfilling the gaps identified in existing LCI databases limited to location specifications and associated climate factors etc. The methodology is LCA based, and follows the basic steps of LCA as discussed in Sect. 2.1. The approach is more focused on collecting data from manufacturing processes and more of unit process oriented, although sub processes are also taken into consideration. It comprises of three methods: Screening approach, In-depth approach and combination of two [14]. Screening approach is mainly based on engineering (mass loss and energy) calculations and the in-depth approach is mainly based on industrial process measurements [14].

2.3 Thermodynamics Approach

The thermodynamics approach uses loss of exergy as a measure to quantify impacts during whole life cycle of products. The exergy content of a material is the maximum amount of energy which can be transformed into work at given environmental conditions [16]. It is also a measure of dissipated impacts (emissions) of the rejection of useful energy and depletion of material resources in exergetic terms [16].

2.4 Sustainability Characterization Methodology

This methodology stresses more on scientific basis for assessment of manufacturing processes from sustainability point of view. A well defined approach to characterize sustainability for manufacturing is missing [4]. This approach is again more focused on manufacturing process data and addresses the gaps in existing assessment methods. A set of quantifiable key performance indicators (KPI) and sustainability indicators are identified which are more important from manufacturing point of view. A relation between process information and its performance has been established. The steps of the methodology as mentioned are: (1) defining systems KPIs and common computable sustainability metrics; (2) developing formal information model that defines the analytics for computing the manufacturing process sustainability; and (3) generating manufacturing process-specific data-sets that instantiate the information models and enables execution of computable metrics [4].

3 Comparing Product Life Cycle Assessment Methods

3.1 Comparison on the Basis of Challenges in Development of Measurement Science

The basis for the comparison of existing product life cycle assessment methods is adapted from the challenges identified by Mani et al. [4] as the study identifies uncertainties, challenges and difficulties in decision making in widely used product life cycle assessment practices, specifically for manufacturing. The comparison of four methods discussed earlier with respect to the challenges (as shown in Table 1) finds out, in which areas existing methods are deficient in addressing them. The challenges identified by [4] to develop the measurement science for sustainable manufacturing includes:

- Uncertainties in manufacturing environment; depending upon the customer requirements, manufacturing environment is classified into four general categories: make to stock, assemble to order, make to order, engineer to order. Uncertainty in such environments caused due to change in demand, designs, customer requirement etc. [17].

Table 1 Comparing existing life cycle methods based on challenges to develop measurement science for sustainable manufacturing (challenges adapted from Mani et al. [4])

Challenges in development of measurement science for Sustainable Manufacturing									
Product life cycle assessment methods	Uncertainty in manufacturing environment	Dramatic changes in customer requirements	Innovation in production technology	Uncertainties in internal operating environment	Inadequate and unstructured information	Undefined scope and boundaries within UMP	Multiple unverified measurement methodologies	Inadequate decision models	Inadequate approaches to overcome uncertainties
Life cycle assessment [9]	Not addressed	Not addressed, no real time process measurements	Not addressed	Labour practice, decent working conditions addressed in SLCA	Standard data formats; Ecoinvent (2011), ILCD (2011)	Data is aggregated and generalized	Not addressed	Criticized Single values based decisions e.g. Eco-Indicator, Eco points.	Addressed by means of sensitivity analysis, approximation and Monte Carlo simulation
UPLCI $CO_2PE!$ methodology [14]	Not clearly addressed, Variability through parametric emission estimation models	In depth approach measures individual process data	Not addressed	No metric considered to address such uncertainties	Data formats useful for LCI	Unit process level including the sub processes and only use phase of machine tool	Suggested more accurate measurements in the In depth approach by industrial process measurements	Not addressed	Slight focus by means of process specific data collection
Thermodynamics approach [16]	Individual process data estimation		Not addressed	No metric considered to address such uncertainties	Not addressed	Individual process level			Not addressed
Sustainability characterization methodology [4]	Through process data collection from various Sources	Not certainly, Through process specific data sets created from various sources	Not addressed	No metric considered to address such uncertainties	Structuring information using information models	Depends on UMP specific data collected from Sources, handbooks, catalogues etc.	Data from UMP specific data sources, depends on source; Not addressed	Decision support system, decision alternatives	

- Dramatic changes in customer requirements, which in turn again accounts for change in manufacturing environment.
- Innovation in production technology; Industry automation, cloud manufacturing, cyber physical systems, which makes the existing data useless.
- Uncertainties in internal operating environment; circumstances, working conditions that influence performance.
- Inadequate and unstructured information; which is an obstacle in decision making.
- Undefined scope and boundaries within manufacturing unit processes; to which level of sub processes, data is being collected.
- Multiple unverified measurement methodologies; variants of LCC [11], vast number of available assessment methods as listed in [8].
- Inadequate decision models; resulting from the unstructured information of assessment results, improper documentation of data sources [4].
- Inadequate approaches to overcome uncertainties; uncertainties in data collected, location based data collection etc.

Uncertainty in manufacturing environment is not clearly addressed by any of the prescribed methods. Dramatic changes in customer requirements of the customers causes change in processing of products, process specific data is thus necessary. LCI databases uses data collected from various industries, which may not be applicable to all processes. UPLCI CO_2PE! methodology attempts to fill these gaps by collecting process specific data and clearly documenting climatic and environmental factors. Also innovation in production technology such as industry automation, cloud manufacturing has not been included in any method till now. Such innovation can cause drastic change in processing methods and existing data will no more be valid. Only s-LCA focuses on social impacts, but they are limited to impacts in manufacturing environment only. Social impacts are beyond the scope of other methods discussed. Structuring the information has been attempted under LCA approach and recently by Sustainability characterization methodology by suggesting use of information models. Scope and boundaries definition has always been a crucial step in assessment methods. Only CO_2PE! methodology clearly attempts to document the details at which level measurement study is to be carried out. No method addresses verification of measurement methods to much detail. Decision model support system is talked about by Sustainability characterization methodology. Uncertainties in manufacturing are not addresses by any of the method.

4 Discussion

In Sect. 3, comparison of four product life cycle assessment methods is done with respect to challenges identified as mentioned in earlier sections e.g. uncertainties in manufacturing and operating environment; changes in requirements; information, boundary, decisions and methodology related issues etc. [4]. From the comparison

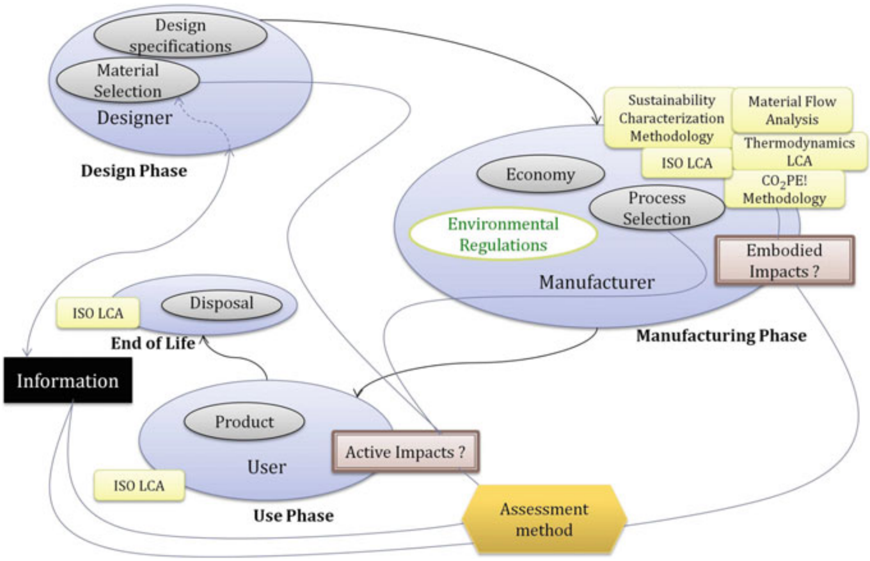

Fig. 2 Methodological basis to compare manufacturing processes for design decisions

it is clear that none of the existing method addresses all challenges related to manufacturing. Data collection and reliability of data related issues are addressed and attempted to resolve by $CO_2PE!$ methodology, which may otherwise lead to wrong decision making. Lack of decisions support and unstructured information related issues are addressed by sustainability characterization methodology. Methodologies discussed in this study majorly try to address limited impacts of products during manufacturing phase, in various dimensions i.e. environmental, economic or societal. Use phase impacts including active impacts could be higher than the embodied impacts. There is little evidence that any method assesses the active impacts of a product which are however equally important.

Recent advances in LCA show some development in the area of social impacts. For development of an integrated methodology, shortcomings of the existing practices e.g. assessment of active impacts, need to be overcome. A set of impacts traceable to manufacturing are required to be identified. Figure 2 shows basis of proposed methodology including all life cycle phases of a product and impacts associated. It also illustrates disconnect in prevalent methodologies adopted and their scope. Active impacts can be recorded based on behavioral and consumer responses in terms of threats traced from manufacturing point of view. Embodied impacts in manufacturing related to energy, water and resources used can be assessed using existing approaches. UPLCI—$CO_2PE!$ initiative is a promising approach for data collection on environmental impacts of manufacturing [18]. Resulting method can contribute to understanding of impacts caused due to manufacturing and can be used as a decision making tool to compare manufacturing processes.

5 Conclusions

This study examined existing product life cycle assessment methods and compared them to find out the gaps where they lack in assessing impacts of a product life cycle. Existing methods hardly focus on tracing active impacts to manufacturing activities. Future studies may include addressing all the gaps discussed in this paper and an integrated approach for assessment of all impacts in greater detail by characterizing manufacturing processes based on impacts traceable to manufacturing processes. Such method will contribute to better decision regarding the selection of manufacturing processes for environmentally benign designs.

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Application of InDeaTe Design Tool for Designing Sustainable Manufacturing Systems—Case Study of a Micro-hydel Turbine

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Abstract The InDeaTe design tool was developed to help designers and engineers to innovate by following a methodical process. This paper discusses the application of InDeaTe for designing a manufacturing system for a grassroots innovator who makes and installs small hydel power turbines in southern India. The aim of the design exercise was to help scale up the current manufacturing setup to cater to the high demand, while ensuring its sustainability. Two design teams were involved in solving the problem—one using the tool and the other without. Analysis of the final design outcomes showed that the team using the InDeaTe tool generated a more comprehensive design than the team not using the tool. This study indicates that InDeaTe tool can help in developing more inclusive designs for manufacturing systems. Future work on InDeaTe includes improving its usability and expanding its database.

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1 Introduction

About 237 million in India still do not have access to electricity as the grid still does not reach its remote areas [1]. Renewable sources of energy such as micro-hydel, solar, and wind depend on the location and geography, hence play an essential role to provide decentralized accessibility to energy. The estimated potential for micro-hydro projects in India is about 20,000 MW [2]. A hydro power turbine converts the energy from falling or flowing water into rotational mechanical energy. The selection of the best turbine for any particular hydro site depends upon the site characteristics, like available head and flow, and on the desired outputs like running speed of the generator and power load [3]. In most cases, a small hydro power plant is 'run-of-river'; i.e. a small barrage, usually just a weir, and generally with little or no storage of water. The civil works are merely for regulating the level of the water at the intake to the turbine. Therefore, run-of-river installations do not have adverse effects on the local environment like large hydro power plants [3]. While there is still no internationally agreed definition, anything between 10 and 200 kW is called a micro-hydro power plant, whereas anything less than 10 kW is called a pico-hydro power plant [3, 4]. In this study, we refer to anything less than 200 kW as micro-hydro.

The remote regions of Karnataka are power-starved as they cannot be connected to grid; nevertheless, the beautiful landscapes are laden with perennial natural water streams. To deal with the problem of electricity access and uncertain power supply, micro and pico-hydel power turbines are being used as alternative sources of energy. One grassroots innovator has been making and installing customized micro-hydel power systems of 1–10 kVA capacity through trial and error. There is tremendous potential for this product in hilly areas of the country, especially in the south, far north and north-east. In order to meet the anticipated demand, the subjects in this study were asked to design a sustainable manufacturing system to scale up the production of such turbines for the grassroots innovator. The resultant designs were compared to assess the improvement for sustainable manufacturing considerations, with and without the use of the InDeaTe Tool.

2 Design Exercise

2.1 Exercise Summary

The design exercise was undertaken in June 2015 at the Centre for Product Design and Manufacturing (CPDM), Indian Institute of Science (IISc), Bengaluru. The design problem was introduced by a representative from National Innovation Foundation (NIF), Ahmedabad. The exercise was conducted in two sessions with a separate team in each one using the tool and the other without. The design outcomes were presented and feedback was taken from NIF. The design outcomes were primarily analysed for improvement in sustainability of the system.

2.2 Exercise Duration

The exercise was approximately for 16 h, spread over two consecutive days:

Day 1—Introduction to Problem and Task Clarification;

Day 2—Conceptual Design and Embodiment Design.

2.3 Design Teams

Composition of the two teams was as follows:

Team 1 using the tool comprised two senior PhD students and one Undergraduate (UG) student in engineering.

One senior PhD Student, from IISc, was working on Design for sustainability, with background in Mechanical Engineering and Product Design.

The other senior PhD Student, from UC Berkeley, was working on Hydrogen fuel cells, with background in Mechanical Engineering.

The UG student was pursing B.Tech in Production Engineering from IIT Roorkee, India.

Team 2 without the tool comprised three junior PhD students and one Undergraduate student.

One junior PhD Student, from IISc, was working in the area of Network-enabled Manufacturing, with background in Mechanical and Biomedical Engineering.

One junior PhD Student, from IIM Ahmedabad, was working in the area of Water-Energy nexus for sustainability, with background in Environmental Engineering.

The other junior PhD Student, from WSU Pullman, was working in the area of Life Cycle Assessment (LCA), with background in Mechanical and Civil Engineering.

The UG student was pursing B.Tech in Mechanical Engineering from IIT Ropar, India.

3 InDeaTe Tool

There are various kinds of design support that focus on sustainability; however, most of these are for assessment and evaluation, such as the Swiss Ecoscarcity methods (Ecopoints) [5]. Certain tools such as DFE Workbench [6] are well-integrated with Solidworks CAD tools, and are able to support designers with respect to specific aspects of a design, environmental aspects in this case. There are other design methods that support only a specific phase of the Life Cycle e.g. the Use-phase [7].

Interaction of methods and tools at the various steps in the process of design has been noted in literature, and the need for interaction between design methods and computer-aided tools to support decision-making has been stressed [8]. Lopez-Mesa [9] enumerated potent findings about the knowledge and use of design methods in practice; she highlighted that very few methods are widely and systematically used, while most people are not aware of the availability of other methods, or believe that a large amount of time is required to use these methods. However, she notes that application of methods supports an array of tasks during the design process and leads to consideration of a large number of ideas. Lopez-Mesa further stresses that a method contributes better to the design when it is within a computer based system [9]. Thus, there is need for computer-based support that covers all three pillars of sustainability—environment, society and economy—across the entire life cycle of the object of design, and addresses the need for improving sustainability of existing systems, with the systematic integration, to practice, of methods and tools.

The InDeaTe Tool [10] is a knowledge-driven support for designing sustainable products, services and manufacturing systems. It comprises a design process template and a database that work together to support designers through a computer interface. The template is developed from the ACLODS framework [11] as the basis, which presents a new paradigm of design in terms of the dimensions of Activities, Criteria, Lifecycle (LC) phase, Outcomes, Design Stage and Structure. The tool introduces the user explicitly to some of these dimensions, viz. Activities, LC phase and Design Stage, before prescribing the Template. The template offers an overview of the design process and provides a generic guideline to follow during the process. Four stages of design have been prescribed Task Clarification, Conceptual Design, Embodiment Design and Detail Design [12]. Every design has up to five Life cycle phases: Material extraction, Production, Distribution, Use and After Use. The Template encourages designing for the entire LC of the product, with the aim of making it more sustainable. At any point in the design process, designers perform one of these four activities Generate, Evaluate, Modify, and Select; abbreviated as GEMS.

The database consists of sustainability definitions, sustainability indicators and design methods, tools and principles. The definitions are meant to help clarify the design task at hand with respect to the sustainability perspective adopted, while the corresponding indicators prompt the relevant sustainability considerations in the design. The methods are intended to aid the designer in the design process to achieve these sustainability considerations. The tool is a platform where the template is introduced and the details of the design exercise, such as problem brief and details of participants, etc. are collected into a document for future reference. Before starting the design exercise, the user selects the type of design; the InDeaTe tool currently supports design of products, manufacturing systems and service systems.

4 Solution Without Tool

The team without the tool first analysed the current situation, taking into consideration the market conditions, policies and socio-economic aspects. They identified the criteria and categorised these as per the triple bottom line. Requirements and solutions were identified for concepts as per the life cycle phases. Finally, recommendations were made for design, manufacturing techniques and supply chain activities for the turbines. The following section presents the process undertaken to arrive at the final outcome.

4.1 Current Situation

As per the problem brief given by NIF, the existing market demand of micro-hydel power plants in the state of Karnataka and regions in the North-East was estimated to be around 2000, with an overall market potential of 8000 micro-hydel turbines in India. The grassroots innovator is currently able to supply only two customized turbines per month, so the annual supply runs at 24. There are very few grassroots suppliers that can supply cost-effective and sustainable turbines, so the demand will remain more than its supply. Additionally, BSNL, a public sector telecom company, has expressed interest in setting up micro-hydel power plants to power 100 cell towers in the remote regions of Karnataka.

The team considered the market condition along with other parameters such as the current policies and technology available in the country. In the current scene, there is no competition for the innovator in micro-hydel systems; however, there remains competition in terms of cost, efficiency, durability and accessibility from other sources of energy such as diesel, solar and wind. Solar and wind cannot compete with diesel in terms of easy accessibility. However, with subsidies and national and state push on renewables, they will become competitive in terms of costs. The innovator has been foreseen to dominate the market if he scales up his operations. However, with market expansion, problems of durability and service would occur after installation. Unlike diesel generators, skilled personnel are required for operation and maintenance of micro-hydel power system to be sustainable over longer period of time. Additionally, there remain socio-cultural challenges in terms of acceptability, economic challenges in terms of affordability, and technical challenges in terms of efficiency and use for such systems with increasing number of electrical appliances. Both end users and vendors need to be educated and be aware both about the product and its operation and maintenance.

4.2 Criteria

The principle selected by the team without tool to work on the problem was triple bottom line, as it factored for sustainability and looked into its three main pillars: (1) Environment, (2) Economics and (3) Society. The environment parameters considered are resource use, pollution in the form of emissions and effluents, and their impact on human as well as natural ecosystems. The economic parameters considered are cost and efficiency of the technology, market conditions for diffusion of the technology and development of local economy. The social parameters considered are social responsibility of manufacturers, vendors and users.

4.3 Ideas for Improvement

The team went through several design stages in order to arrive at an understanding of the problem and getting a structure to solve it. They considered the life cycle phases of the turbines: material extraction, production, distribution, use and after-use. The team followed the life cycle phases as a couple of the students were familiar with the concept. The group then deliberated on each of the phases and the elements required for the given problem. The material extraction stage involved looking into issues such as local sourcing of materials for manufacturing the power systems. The aim was to redesign with less, but quality material, and use of recyclable and reused materials and parts. The production stage had to be revamped, as the main objective was to scale up the process. The team had to redesign the process to make it easier for the manufacturer, and also easier for assembly/disassembly before and after use. The process of scaling up required more manufacturing locations, and efficient and cheaper transportation and distribution systems. There had been problems faced in the operation and maintenance of the product, which the innovator was able to deal with as the clientele was small and local. With scaling up, the innovator would need to look into long term operations, and safety during use. Additionally, the group had to minimize downtime and during disasters. In the after use stage, aspects such as design for disassembly, incentivising recycling, and programmes to encourage secondary market for robust parts having longer lifecycles were considered.

Elaboration of major ideas: Three of the several solutions discussed in each of the life cycle stages, over 8 h, were narrowed down by the group to improve the process design. These were the following.

1. **Decentralize Manufacturing**: The group recommended a hub and spoke model which encourages creation of manufacturing hubs, one each in Karnataka and North-East. This should be followed by building smaller hubs to facilitate transportation and distribution of the power systems in smaller towns, with final assembly taking place on-site. This should reduce packaging and generate more jobs at the smaller hubs.
2. **Standardize Designs/Components**: The design of the power systems in each of the 1, 2, 5 and 10 kVA capacities vary considerably. This required customized manufacturing and availability of raw material. In order to scale up, there is a need to standardize a proven design for the generator set in each capacity. This in turn will increase manufacturing efficiency (making a lot of the same is easy), minimize number of spare parts to deal with, and ease the repair process during operation and maintenance.
3. **Improve Cup Design**: The cups of the pelton wheel provided in the pictures above vary in size. The design of cups like the generator set needs to be standardized in order to improve efficiency and make it easier to manufacture at less energy and costs.

5 Solution with Tool

The team using the template identified the scope, the issues to focus on, and the list of requirements for clarifying the task using the methods given in the database. Production and use were identified to be the most critical life cycle phases; hence, relevant indicators were chosen to improve these phases. The weighted objectives method was used to prioritise the requirements. The team generated several concepts, of which one was selected by consensus. The 6R principle was followed throughout.

5.1 Task Clarification

The main objective of the solution was to create an affordable manufacturing system that does not compromise on the performance of the turbines. The size, materials, layout and energy generation technology were all recommended to be changed according to the design. The principle, indicators, life cycle phase, components to be changed, and the requirements are listed below.

Principle: The main principle chosen to improve the process design was 6R which is an acronym for reduce, reuse, recycle, refurbish, redesign, and repair.

Indicators: Indicators were chosen based on the selected principle. These include: resource use, environmental indicators (climate change, GHG), production cost, employment, flow rate, raw materials, energy input, energy efficiency, energy consumption, raw materials, quality, and less materials.

LC Phase: As mentioned earlier, in order to improve the process at minimum costs, production and use (operation) phases of the lifecycle were chosen as they both ranked high in priority areas that needed attention for sustainability.

Components: The components chosen to work on the design were the supporting Frame, and the main focus was on Pelton wheel due to lack of time.

List of requirements to improve the Pelton wheel are as follows:

1. Pelton Wheel manufacturing process standardization;
2. Safety (during installation and use);
3. Scales of MHET for different requirement profiles;
4. Alternative use of drive.

Method Used: The methods used to narrow down the aforementioned choices were weighted objective method and expert opinion.

5.2 Conceptual Design

Ideas were generated, evaluated and recommended for the following requirements.

Standardization:

- Scales of MHET for different profile requirements: different head requirements for varying geographic locations
- Provision to add more weights to the flywheel
- Provision for variation in the supporting frame
- Standardizing for supporting frame and wheel
- Increasing diameter of flywheel
- Variable diameter wheel.

Safety:

- Installation
- Use/operation.

Alternative uses of drive and generated electricity (add on):

- Flour mill
- Agriculture purpose: sowing/irrigation
- Ideas from Power Take-Off of Tractor.

Inputs from the innovator:

For standardization, the 1 and 2 kVA units are very similar and they have larger volume requests than other units. The 1 kVA turbine has 18 cups on a flywheel of diameter 1.5 feet and weight 20–30 kg. The 2 kVA turbine has 26 cups on a flywheel of diameter 2 feet and weight 40 kg. The main challenge faced by the

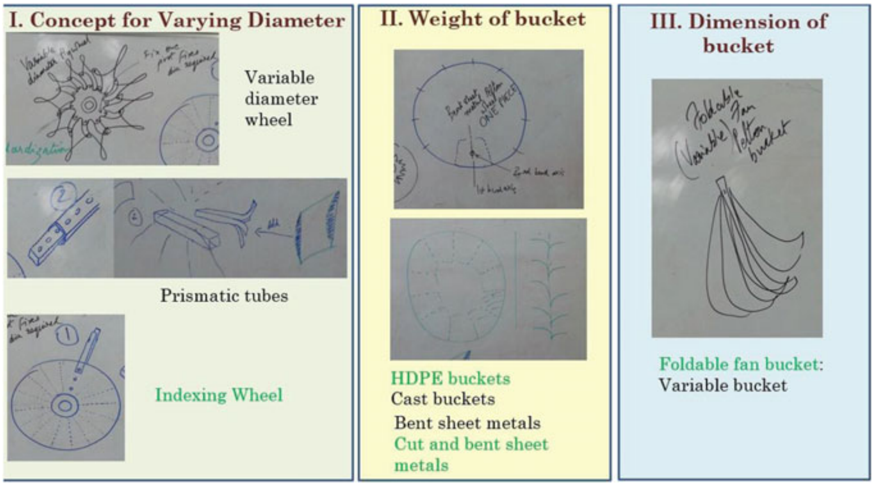

Fig. 1 Concepts generated by the team using InDeaTe tool

innovator was to standardize for Flywheel Weight, Bucket Variation, Pelton wheel, and Alternator. Concepts for the Pelton wheel were generated, see Fig. 1. The design of the diameter and type of wheel, the weight of the bucket and dimension of bucket were discussed as an example to improve the design of the wheel.

5.3 *Embodiment Design*

Due to lack of time only two of the generated concepts in varying diameter of the wheel were compared. They both have foldable fan buckets mounted on the indexing wheel; one has buckets made of HDPE while the other has buckets made of Sheet metal. The first concept, consisting of Indexing Wheel, Foldable Fan Bucket and Bent Sheet Metal buckets was suggested as the solution based on consensus. If more time were available, this would have led to conducting comprehensive analyses in each of the selected phases and generated concepts. Provision of time frame during this stage alongside the methods used can be helpful to the users of the database.

6 Analysis of Design Processes

In this study, the controlled variables include the participants' educational background to a certain extent, the given problem, expert intervention, template of the tool and the associated database, whereas the uncontrolled variables consist of the participants' prior experiences, individual and group dynamics. Although the team using the tool did not explicitly refer to any particular definition of sustainability, they chose all the indicators related to production and use phase. The team without tool did not know how and where to begin and lacked structure in their approach. They felt that having specific goals would have helped to focus and avoid the initial day confusion which resulted in a slow start. In the absence of structure, the group ideas argued on solutions without identifying requirements. They, however, followed the triple bottom line principle [13] and life cycle analysis as method, to generate ideas as per the five phases of the life cycle. Their familiarity with these concepts could be attributed to their educational background. On the other hand, the team using the tool focused on certain specific requirements after prioritisation, but they could not evaluate the solutions generated due to lack of time.

The team without the tool did not use formalised methods to identify the task and evaluate the requirements as they had no structure resulting in generalized suggestion over all the phases. The team using the tool used the weighted objective method for selecting the most promising requirements. They generated ideas by brainstorming and selected the most promising solution by consensus. Owing to insufficient data and time constraints, they were not able to perform any detailed calculations. Life cycle cost analysis (LCC), vulnerability assessment (VA) and Social Impact Assessment (SIA) were recommended if more time was provided.

7 Conclusions

This study suggests the importance of method and structure in solving a design problem. InDeaTe tool was able to provide the group of designers and engineers to comprehensively solve a problem at hand by prioritizing based on time, cost and principles of sustainability. The solution provided was observed to be deliberated on in a more systematic manner. The team without the tool struggled to get a structure resulting in loss on time. They ended up discussing solutions, without discussing the purpose of the solution. The experiment showed that a skilled person without design background will find the tool difficult to follow. The tool is primarily meant for designers, and there is a need to make making it more user-friendly and to include other set of skilled users (like engineers). Providing tutorials and training modules will give it a broader appeal, thereby making it available to users without a design background. There is a huge scope for improvement in the database, which should be made more comprehensive, so that a wider range of possible scenarios, time-frame and difficulty level could be addressed during the design process. Future work will involve applying the tool on a wide variety of manufacturing system design problems, in addition to improving the database and its usability aspects.

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Supporting Manufacturing System Design: A Case Study on Application of InDeaTe Design Tool for a Smart Manufacturing System Design

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Abstract InDeaTe is a Design Tool that aids the designer by empowering ideation through a methodical process of design. This paper presents the evaluation of the tool through a case study on a manufacturing system design problem conducted in University of California, Berkeley. The problem given was to design a 'smart' manufacturing line for a lawnmower shaft. Four designers participated in the exercise, in teams of two each; one team used the tool and other did not. Design outcomes were compared. Analysis of the results showed a larger number of ideas generated by the team using the tool compared to the team without the tool. This study, although conducted over a short period with limited number of designers, illustrates the potential of the InDeaTe tool to address manufacturing system design problems by not only developing a richer subset of design outcomes, but also by taking into account sustainability considerations throughout the product life cycle.

Keywords Smart manufacturing · Design for sustainability · Enabling technologies and tools · InDeaTe tool

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1 Introduction

This paper describes a case study conducted to systematically evaluate the influence of following a structured design process and methods using InDeaTe tool than without using the same. Structure of the paper is as follows. Section 1.1 provides motivation behind choosing smart manufacturing system design as the problem domain, Sect. 2 introduces the research objectives and the problem brief, Sect. 3 introduces the InDeaTe tool; describes design exercise carried out using the InDeaTe tool and without using the InDeaTe tool, Sect. 4 includes analysis of design process, Sect. 5 covers evaluation of the outcomes of the exercise, Sect. 6 summarizes the work and reflects on the effect of the InDeaTe tool.

1.1 Focus on Smart Manufacturing System Design Problem

With ever increasing tension between consumer demands and natural as well as engineered resource depletion, some of the most advanced economies are seeking to revolutionize their manufacturing competencies through smart manufacturing [1]. Such blending of the physical and cyber worlds is expected to open up doors for innovation that has the potential to optimize the entire manufacturing sector to improve quality, flexibility, productivity, and energy efficiency without compromising on sustainability. The National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce, and a strategic leader in this area defines Smart Manufacturing as systems that are "fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs [2]. Realization of smart manufacturing involves the integration of several technologies such as the Internet of Things, big data analytics, multi-scale dynamic modelling and simulation, networked sensors, Cloud computing, 3D printing, smart factories, smart grids, interactive visualization, data interoperability, and scalable multi-level cyber security [3].

This case study was conducted at the Laboratory for Manufacturing and Sustainability (LMAS), University of California, Berkeley. Smart manufacturing research at LMAS focuses on big data analytics [4] and data harnessing from advanced sensor systems [5].

2 Research Objective and Methodology

The research objective is to evaluate InDeaTe tool through a case study on a manufacturing system design problem. The research methodology included a series of design experiments to evaluate the effectiveness of InDeaTe on a broad set of problems that includes product design, manufacturing system design, and service system design. These problems were attempted with and without using the tool by different teams, and the process and results compared for assessment of tool efficacy.

2.1 Problem Statement

The problem statement, provided by LMAS, is as follows: the transmission shaft of a particular lawnmower is manufactured by three different processes, on three different machines, in the following sequence: CNC Turning, CNC Milling/Drilling, and Grinding. The participants were asked to Design a 'smart' manufacturing line for an automated machine shop for making this shaft. The machine tools have several sources of data, and many of these data sources are wireless sensors which run on batteries. The manufacturing line should meet the following requirements.

(a) Easy market adoption—how can an existing manufacturing line be converted into a 'smart' manufacturing line without revamping the locations of all of the machines?

(b) Charging station—Wireless sensors running on batteries need to be charged regularly. What is the minimum battery life needed so as to be unobtrusive in an existing manufacturing line? How can this be made easier? How can the charging of sensors be made effortless and easy in the manufacturing environment?

Faults, failures, and manufacturing issues, what does a revamped manufacturing line look like? What are the activities that still have to be performed manually? What skill levels change? Are smart phones needed for monitoring and is that something that can be adopted today?

3 Design Exercise

The design exercise started with an introduction to the design problem. The exercise was conducted with two teams—one using the InDeaTe tool and the other without using the tool. The outcomes from the two design exercises were then compared. Each design exercise lasted approximately 32 h, spread over four days. The InDeaTe tool is described below, followed by the process and outcomes of the design sessions carried out without and with using the tool.

3.1 InDeaTe Tool

The InDeaTe Tool is a knowledge-driven support for designing sustainable products, services and manufacturing systems. It comprises a design process *template* and a database that work together with a *database* of methods and tools, to support the designers through a computer interface. The template is derived from the ACLODS framework [6], which presents a new paradigm of design in terms of the following dimensions: Activities, Criteria, Lifecycle phase, Outcomes, Design Stage and Structure. The tool introduces the user to some of these dimensions—Activities, Lifecycle phase and Design Stage—before prescribing the Template. The template offers an overview of the design process and provides a generic guideline to follow during the design process. Four stages of design are prescribed—Task Clarification, Conceptual Design, Embodiment Design and Detail Design [7]. Every design has up to five Life cycle phases: Material extraction, Production, Distribution, Use and After Use. The Template encourages designing for the entire lifecycle of the product, with the aim of making it more sustainable.

3.2 Solution Without Tool

3.2.1 Task Clarification

As a review of the design problem indicated multiple issues at system level, designers felt it necessary to identify significant issues that could be realistically addressed within the limited time and resources. Among all the sources of information available, eliciting information from domain experts were considered to be quicker and relevant as experts, having worked on various aspects of the problem at level of systems and subsystems, should be able to provide inputs that would serve in narrowing down the area of focus.

3.2.2 Use of Expert Interview for Task Clarification

Through an expert interview, it was inferred that charging sensors was the most significant issue. Given the resource and team constraint team felt it would be worth addressing one issue in detail instead of attempting to different subsystem of the problem. Therefore, the team decided to focus on addressing the issue of charging. In order to direct the design effort only on the charging issue, the modified problem statement deliberately excluded the other chunks of the problem that did not have a relationship with the issue of charging. In order to have a larger solution space, the problem statement was abstracted and defined in a way that potentially avoided any early design fixation.

An important step in the problem solving approach was defining the problem in a solution neutral way Pahl and Beitz [7], something that the designers involved had learnt from their masters level product design courses. An underlying objective behind this approach was to define the problem at an abstract level without being committed to any particular solution. For instance, defining the problem as “designing a charging device for sensors” could potentially fixate the solution space to the electrical domain through the word “charging”, which would reduce the search for new ideas from an another domains such as biology or archaeology.

3.2.3 Solution Neutral Problem Statement

Design an unobtrusive, easy to use, energy transfer device

3.2.4 Idea Generation and Conceptual Design

For solution space generation, one of the methods used was bio-mimicry. The designers employed this methodology using Ask-Nature [8] as the source of information. Ideas generated included sensors that would work on number of solution principles such as (a) converting thermal energy produced from heat dissipation from the tools to electrical energy (b) using generator coils around rotating elements to harness energy; (c) using power from electrical supplies provided for the machine itself; (d) using photovoltaic coatings on bearing surfaces; (e) using light harvesting nano-structures, and (f) using noise to generate energy.

3.2.5 Detailed Design

Concept selection was done using relative weighing of concepts and with a review by experts with respect to energy efficiency and ease of market adaption. The final selected concept included systems that harnessed energy from vibrations and sound and converted these to electrical energy.

3.2.6 Design of Sensor Network Interface Architecture

For a manufacturing system, the engineers using the system needed continual indication on the energy level and the spatial location of the sensors in the system. This is accomplished by a dashboard with a modular architecture that is compatible across various devices such as digital monitors in machine control rooms, laptops and mobile devices. Figure 1 shows the on-site monitoring system via a mini-dash, available as a device or an app on a smart phone/pad, with the basic information required for repair, service and calibration. This minimised the need for high level of skills for the labour required. The proposed automatic turn-off mechanism of the sensor through control switches was expected to improve energy efficiency through avoiding charge run off.

3.3 Solution Using the Tool

The team using the tool followed the steps described in its template which starts with the Task clarification stage.

3.3.1 Task Clarification Task clarification begins with identifying the system boundary to scope out the problems beyond the purview of the design. This step is

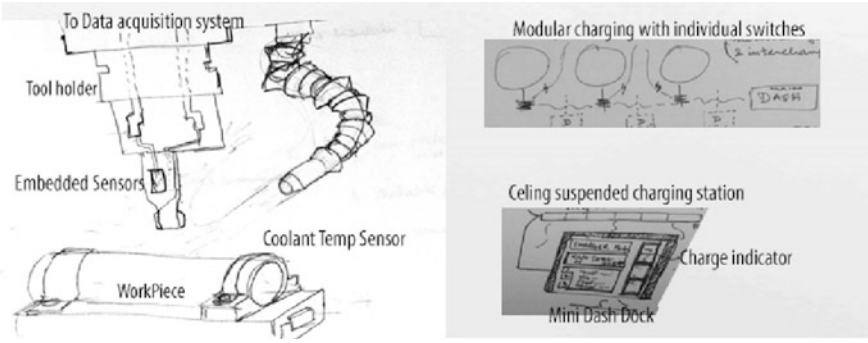

Fig. 1 Proposed configuration of a sensor charging system and interface

followed by describing the issues within the system boundary, followed by identifying the stakeholders with an influence on the problem, and identifying the flow of work through flow analysis. In the following paragraphs we describe the outcomes of carrying out these steps.

3.3.2 System Boundary Manufacturing processes that were not allowed to be changed were CNC Turning, CNC Milling/Drilling and grinding on different machines. The variables identified were interactions among between the machines, activities performed by the operators, data collected and used, and decisions automated.

3.3.3 The Issues identified after analysis of the current situation were as follows: Manual monitoring of machines and processes; bad quality production due to degraded cutting tools; downtime due to (a) maintenance (b) tool failure (c) non-availability of operator, and (d) non-availability of appropriate materials.

3.3.4 The Definition of sustainability used was from the U.S. Department of Commerce. It defines Sustainable manufacturing as 'creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers.' The methods shortlisted for identifying requirements were Stakeholder mapping, House of Quality, Flow analysis and 6R.

3.3.5 Stakeholders were identified were: Organisation, Employees (operator, line manager, shop supervisor, upper management), suppliers, clients/customers, and transporters.

3.3.6 Flow Analysis Identification of life cycle processes and mapping of material flow has been carried out to chart out critical processes and activities that govern manufacturing system. A preliminary conceptual map of material flow as, has been constructed starting embracing life cycle thinking concept. We acknowledge that the Figure is missing essential quantitative material and energy flow information to be termed as material flow analysis diagram. We are currently imitated by lack of quantitative data at early state of design, such as amount of material flow or energy consumption to generate detailed material flow diagram.

3.3.7 List of Requirements All these steps helped in clarifying the design requirements and defining the problem precisely. Each requirement was categorised into a demand or a wish. The demands were the following: automated monitoring of machines and tools, easy Charging of sensors, minimize downtime, and minimize rework or reject components, ensure safe working environment, and avoid bottlenecks between sequential processes.

Wishes considered were the following: automated tool change after tool failure, indication of optimum tool changing time, minimize coolant use, minimize scrap generation, minimize quality checking (or automate it), easy market adoption.

3.3.8 Solution Neutral Problem Statement 'A manufacturing line that optimises production and minimizes resource consumption while ensuring quality, ease of maintenance and good labour practices.'

3.3.9 Conceptual Design The conceptual design stage determines the principle solution for a given problem. After task clarification, brainstorming was done for each requirement. Using the ideas generated during brainstorming, Morphological charts were used to generate solution variants. The requirements were compared with each other to identify their relative importance, denoted by their weighing factors. Then the solution variants were evaluated for each requirement using weighted objectives method and scores were calculated. The variant with the best score was chosen as the concept.

4 Analysis of Design Processes

During the task clarification phase designers were frequently referring to the InDeaTe tool for following the systematic design process and identifying information related to the each process. The design team using the tool was not particular about the definition, as long as it covered the triple bottom line. Sustainability indicators, although not used while solving the given design problem, gave pointers for identifying a comprehensive set of requirements. Due to scarcity of information available about the design, environmental behaviour of the proposed design throughout its life cycle could not be precisely described.

Brainstorming was carried out for each requirement. Morphological charts were made for combining the ideas generated during brainstorming. However, the ideas in each row of the chart were not independent to one another. There were overlaps between some ideas in the same row.

The Weighted objective method was used for selecting the best concept from among the solution variants. The outcomes of the Team using the tool were reported in a tabular or textual form. This is not a shortcoming of the tool. Since one of the team members was working in the same research area, there could have been some bias, either good or bad. The Morphological charts method was used because of familiarity and ease of application within the time constraint, but better methods were desired.

5 Evaluation of the Exercise with the Template and Without the Template

The objective of the evaluation was to compare the effectiveness of outcomes generated using the template to those without using the template. In order to minimize the influence of domain knowledge, it was assumed that designers had a similar magnitude of training and experience in design related domain. Considering the similar backgrounds of individual designers having masters in design related domain; an experience of 1–2 years was taken to be safe assumption to make. As there were no explicit benchmark for assessing the "quality of the solution" as the problem itself was new, the "number of ideas generated" has been used as a measure of the effectiveness of the outcome.

Analysis of the design documents showed that the number of ideas generated using the tool was 69 and without the tool were 14. The difference may be due to observation that the designers using tool used several methods and hence they might have had more perspectives to analyse the problem that resulted in a larger number of ideas.

However, current measure of effectiveness was limited by the lack of concrete benchmarks for assessing the effectiveness of solution-development methods at the early state of design (Fig. 2).

In order to evaluate the quality of the ideas, we have used multi criteria evaluation method and outcomes are presented in Table 1. The criteria for evaluation are based on the list of requirements mentioned in Sect. 3.3.7. The criteria used are

(a) 'Ease of charging' is described in terms of 'time taken for charging' and 'perceived simplicity of charging system'.

   (i) 'Perceived Time taken for charging' is assessed by energy transfer rate of a technology under consideration. Rating range between 1 and 5, 1 being fastest, 5 being slowest with "Less is better approach". For example an

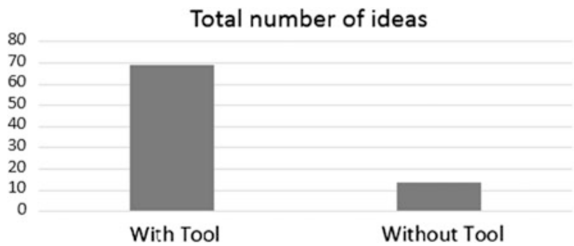

Fig. 2 Number of ideas using the template and without using the template

idea that comprises wired energy transfer has been rated lower than wireless energy transfer technology on the assumption wired technologies can transfer faster than wireless.

(ii) 'Perceived simplicity of charging system' is assessed by likely number of components present in the system. For example: an idea that comprises wired energy transfer is assumed to have more number of components and hence rated higher than wireless counterpart.

(b) 'Perceived Energy efficiency' is assessed by potential of an idea to reuse the energy from the system itself instead of using new source of energy.

(c) 'Novelty' is assessed through score of 3. Score of 1 indicates 'low novelty idea' that do not comprise of any major improvements w.r.t state of the art. Score of 2 indicates 'medium novelty idea' that comprises of Ideas that caters to a new functionality. Score of 3 indicates 'high novelty idea' that uses a new principle to perform the primary functions.

Net effectiveness score is computed by addition of average ease of charging score and perceived energy efficiency. With net effectiveness score of "40.5", novelty score of "14" for the ideas using the template and with net effectiveness score of "41.5", novelty score of "13" for the ideas without using the template our analysis indicates 'no significant difference' in terms of quality of the ideas generated with the tool and without the tool. However our evaluation is limited by knowledge about the potential of these ideas in terms of the criteria chosen and hence inherently subjective.

6 Summary and Conclusions

To summarise, the designers using the tool were able to generate ideas that had the potential for addressing a larger range of issues within given problem and that had the potential to cover broader dimensions of sustainability. Designers using the tool felt InDeaTe provided a common framework for approaching the problem and driving the design conversation forward. However more studies are required for validating the tool in a comprehensive manner. As research advance in the field of smart manufacturing, multi-criteria methods can be used such as novelty and variety of ideas produced for comprehensive evaluation of the outcome of the design experiments i.e. requirements and solutions for smart manufacturing in this case.

Ongoing work on development of the tool includes incorporation of feedbacks obtained from the design exercises, such as resolving usability issues, enhancing the databases and overcoming the limitations of study such as few problems, subjectivity of effectiveness metrics, and influence of domain knowledge.

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Appendix

See Tables 1 and 2.

Table 1 Evaluation of ideas generated using the InDeaTe template with the tool

Ideas on easy charging of sensors using the tool (less score is better principle)	Wired connection to sensor location	Wireless charging for battery	Harvesting energy from ambient light	Harvesting energy from vibration/sound	Harvesting energy from spindle rotation	Harvesting energy from machine movement	Net score
Time taken for charging	2	3	5	5	3	4	22
Simplicity	4	2	4	4	3	4	21
Energy loss	5	4	2	1	5	2	19
Net effectiveness	8	6.5	6.5	5.5	8	6	**40.5**
Novelty	3	2	2	2	3	2	**14**

Table 2 Evaluation of ideas generated without using the InDeaTe tool

Ideas on easy charging of sensors without using the tool (less score is better principle)	Using power from electrical supplies	Using generator coils around rotating elements	Using noise to generate energy	Using photovoltaic coatings on bearing surfaces	Converting thermal energy produced from heat dissipation	Using light harvesting nano-structures	Net score
Time taken for charging	2	3	5	5	4	4	23
Simplicity	4	3	4	4	4	3	22
Energy efficiency rank	5	5	1	2	4	2	19
Net effectiveness	8	8	5.5	6.5	8	5.5	**41.5**
Novelty	3	2	2	2	2	2	**13**

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A Gandhian Framework for Social Design: The Work of Laurie Baker and Hunnarshala

Saurabh Tewari, Nipun Prabhakar and Saurabh Popli

Abstract The paper examines the ideas and works of two architectural design practices, Hunnarshala and Laurie Baker that emerged over a period of time in different geographies. The paper argues that their architectural practices reflect consistent Gandhian ethos and highlight discursive elements of a Gandhian framework. The paper employs a reflexive 'making-sense' of actual, lived experience; reading them as 'texts' using as a lens, the works of thinkers and practitioners in the field of social design, including ideas on grassroots creativity and innovation. As derivation, it advances a unified framework for social design and innovation that transcends distinctions of scale, time, and geography, as a Gandhian framework, where one may contextualize various design and innovation practices within the spectrum.

Keywords Gandhi · Social design · Laurie baker · Hunnarshala · Sustainability

1 Introduction

M.K. Gandhi, the thinker-practitioner is foundational to contemporary India; and his genius lies in locating the search for independence from colonial rule within the search for an authentic selfhood that anchors important moral and ethical ideas such as 'Ahimsa' or Nonviolence and 'Satyagraha' or soul force. It is abundantly clear with the passage of the intervening near-century that these are ideas of eternal significance, thus anointed 'Mahatma' or a great soul. There has been thus, an

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impetus to study ideas and interpretations beyond his canonical contributions, which the present can pursue productively. Current scholarly discourse reflects this engagement.

Gandhi's call for social uplift and internal renaissance were super-scribed by Nehru's, who, valorized an industrial-modernity for India. The legacy of Gandhi's ideas has thus largely remained limited to an economy of icons. In spite of this historical parallax, there are instances where Gandhi's ideas have been developed into meaningful practice in design and architecture. This paper explores selected design practices with reference to the postcolonial world, where Gandhian ideas may anchor a visible fecundity. The paper argues for a new conception of social design, especially relevant for the developing world, as a potential, polyvalent locus for sustainability.

The architectural works of Laurie Baker, and Hunnarshala advance significant notions of social design through an intuitive and un-self conscious reference to the Gandhian oeuvre. These cases have helped us to gather synthetic meanings and ideas, and point towards the possibility of a unified framework where design segues scale and domain, while it reifies culture. Thus, in the authors' opinion, the examples presented offer an a-temporal, a-local, and universal appeal that is a consequence of the deeply embedded and sophisticated way Gandhian ideas are deployed in design.

2 Methodology

In the scope of this paper, Gandhi's important ideas and aesthetics are located through examining accounts, and scholarly and critical works. Ideas of architectural design practices Laurie Baker (author 1); Hunnarshala (author 2); social innovation under the Gandhian rubric (author 1 and 3); are culled and developed from lived-experience, interviews and dialogue with key informants. Ideas of social design and innovation considered from literature inform the discussion. In the end, an attempt has been made to derive themes to propose a Gandhian framework of social design.

3 Social Design

Social design persists from cultural forces. 'Design for real world' resurfaced after designers like Papanek [1] restated the purpose of design as beyond designing novelty and lifestyle products for the elite. The landmark Ahmedabad Declaration [2] in 1979 endorsed by UNIDO and ICSID represents the emergence of the social design in the global landscape of design. In the current literature, Tonkinwise [3] elaborates on the multiple roles of social design seeing it as social activity, condensed into a 'democratic' definition of design, i.e., design by/of/for the people.

The discourse of social design centered on this locus; critics like Papanek [1], Manzini [4] and Thackara [5] call for democratic, collaborative and responsible design. It counters the elitism of mainstream design practice including, architecture. Social design has long existed in India, spurred by Gandhi into a search for economic and spiritual independence; restoring dignity of crafts, textile traditions and highlighting social enterprises.

4 Practices in the 'Social'

Various practices in India reflect Gandhian ideas, and can be said to constitute the discursive. Shri Mahila Grih Udyog Lijjat Papad from Maharashtra is an example in food design, which has empowered women to produce edible and FMCG products [6] that are widely visible in the consumer society. The initiatives of numerous individuals and organizations reflect social empathy; and the field of architecture has also received attention.

Hunnarshala, centered at Bhuj, Gujarat, has developed upon pioneering ideas of social design incorporating community planning, architecture, design of spaces and objects pertaining to artisanal knowledge and production within everyday life. COSTFORD, including the architectural practice of late Laurie Baker, exhibits affinities with Gandhian notions at various levels. These are separated; by an interval of two decades or more, India's vast geography, and comprise the full range of the practice of design from artefactual to neighborhood. Considering the apparent diversity and difference in their oeuvre, the connection between Baker and Hunnarshala seems far-fetched. Below the surface however, are bonds that segue conception, approach and worldview; inevitable perhaps, considering Mr. Sandeep Virmani, one of the founding members at Hunnarshala worked with Baker in the early years of his professional life.

4.1 Hunnarshala

4.1.1 Introduction

A group of concerned citizens working in the field of building methods and artisans' empowerment organized—in the aftermath of the Gujarat earthquake in January 2001, a not-for-profit company, Hunnarshala Foundation for Building/Technologies and innovation, or Hunnarshala. It has worked extensively in the field of post-disaster rehabilitation, conservation, slum rehabilitation, rural development and education. It centers on a belief in grass root innovations, obtained by decentralized approaches and embedded in the community as the basis of long term sustainable development.

4.1.2 Approach, Appearance and Semantics of Building

Hunnarshala comprises an unpretentiously campus, built in 2008 and accepted as ‘bhunga’ (traditional Gujarati circular huts) by the locals. Its form is cohesive with other buildings, and coherent in the arid climate of Bhuj. The building was not designed in one go, but has evolved over the time with inputs coming from artists, artisans, locals and architects. The whole complex is open for all. The parking of the complex also acts as a bus stop for the residents of the nearby areas.

4.1.3 Campus Planning and Architecture

According to Kiran Vaghela, founding member, engineer and designer, the campus layout suggests an Indian bazaar. Buildings are in simple geometrical forms. Ridged roofs, and forms reflect simplicity and swadeshi. The built form is unimposing and of human scale. For the author, the asymmetrical planning centered on a courtyard, and earthy textures bring spontaneity and authenticity to this bazaar. The building complex reflects the frugality in making (Fig. 1).

4.1.4 Material and Construction Methods

A large material palette greets visitors to the complex, with differences in each building. A team of artisans has explored different materials in the making of the campus. The traditional knowledge of artisans segues with the technical to test and improve new techniques and materials. For instance, stone dust, industrial waste, is mixed in soil to build rammed earth walls that give it a white colour. Construction Debris, from disposal sites, is employed in kitchen walls. This specific technique evolved during the post-earthquake rebuilding of Bhuj solving the twin purposes of disposal and construction material. The administration block and reception are built by energy efficient compressed stabilized earth blocks which also known as CSEB.

Fig. 1 Hunnarshala Campus, Bhuj. *Source* Nipun Prabhakar

4.1.5 Social Inclusion in the Building Design Process

Social inclusion is one of the driving purposes of the foundation. It empowers local artisans like Nawab, a riot-affected mason at Muzaffarnagar, who now possess know-how of use CSEB blocks to build cost efficient homes. The partnership with experts effectively enhances the artisanal knowledge base, which provides alternative employment opportunities and real benefits to the community. Satnarayan, a mason from Bihar has been employed with Hunnarshala for his skill in bamboo construction, where innovative techniques were developed/deployed for large scale use, during the rehabilitation of people displaced affected by floods in the river Kosi in 2008. Artisans, who have worked with the organization develop and share their unique skills in building-craft, construction and material. Vice versa, a dialogue invariably develops between architects and artisans working for Hunnarshala with respect to technical know-how.

4.1.6 Practice

Hunnarshala holds a participatory approach paramount in all its projects, exhibiting the commitment to the right means obtainable. The involvement of the users and the knowledge of communities are integral to the design processes. Hunnarshala's own campus at Bhuj showcases how these ideas reflect in/through design. As an organization, it aims to build a more respectful, empowered, equal and resilient community. With a fecund originality, it has developed an approach to architecture that has been cited for its appositeness in the context of resource economy, artisanal creativity, disaster risk and recovery, global Climate Change, and hence sustainability [7]. These issues are addressed through an informal architectural language where material, form, imperatives like recycling, and construction processes segue.

4.2 Laurie Baker and COSTFORD

4.2.1 Introduction

The British architect Laurie Baker arrived in pre-independence India for missionary and social work. A well-documented early encounter with Gandhi led the young Baker to a unique approach in his work. He began by designing chairs for leprosy patients in Chandakh, Uttarakhand. Post-independence, the government engaged him in several public projects like Noor Manzil Sanatorium, Lucknow and the museum building in the Zoological Gardens, Lucknow. Baker moved to Kerala in the seventies and began his practice anew. With the founding of COSTFORD [8], an organization working on cost-efficient construction technology for the rural world, he focused on using alternative technologies and organizational forms for social transformation. Using the 'Hamlet', Baker's residence at Thiruvananthapuram,

Fig. 2 The Hamlet by Laurie Baker. *Source* Saurabh Tewari

which reflects the character and ethos typically, we explore the themes and forms of his architecture (Fig. 2).

4.2.2 Approach, Appearance and Semantics of the Building

The campus reveals itself in several stages and ascribed functions through movement. Exposed brick is sketched over with wild foliage and a sense of being in nature persists. The wooden entrance door and several other terracotta artefacts exhibit the taste of owner towards nature. The architect presents the Hamlet as spontaneously emerging built-form, appearing to grow from the ground [9].

4.2.3 Campus Planning and Architecture

As an early predecessor to the Hunnarshala campus, the Hamlet was constructed in stages. Gently emerging and organic built forms emerge out of the steep site; the first structure was made on the hilltop. The architectural form permits connections between built structures to be flexuous and spatially fluid [9]. The architecture is transparent, and the exposed bricks engage attention. Fluid ceilings, harmonious roof forms and their junctures with vertical walls, exhibit a compelling inventiveness. The overall form conveys an earthiness and closeness to nature.

4.2.4 Material and Construction Methods

Baker's architecture displays a highly intuitive and original understanding of its material properties, building upon the strength of India's rural communities; artisanal craft. His best-known examples combine new and recycled materials with an astonishing versatility, including pioneering technologies, such as light filler slabs now practiced by COSTFORD. As Baker [10] reflects, "Fish tiles from a palace, dormers and roofing wood from a dilapidated house, wood from a jetty and pieces of stone or tile, which he picked up, all juxtapose in harmony", his house displays frugal innovation, a cornerstone of his approach to material, construction and a concern towards resource economy.

4.2.5 Social Inclusion in the Building Design Process

For Baker, the mason and building craftsperson held the highest value in the construction eco-system. Setting aside the 'designer' ego at the drafting table, he positioned himself as a co-worker on his various projects. First, many of the decisions regarding the house design were done with conversations with client. Later, many of the construction decisions were taken on the site in consultation with co-workers. Baker believed in workers' rights and in providing fair wages.

4.2.6 Practice

Baker's material often came from eclectic sources, sometimes construction salvage, and, touched by his inventiveness, his works charted new territory in social design. Highly prolific, Baker created original designs of enduring value and eventually a new discursive strand in architecture. Baker's chief achievement is arguably the counter his oeuvre presents to the formal system of building in India (considered inevitable), which, based on codes and highly standardized products and processes has stifled the emergence of a critical architecture based on cultural, and resource differences. To Gandhi and Baker, the formal system remained the unfortunate legacy of India's long colonial history, and ubiquitous social classes; corresponding notions of 'pucca' and 'kutcha' as evidence of social stratification and caste hierarchy, that both resisted and each developed an individual response to. It can be argued, thus, that Baker's works are architecture of praxis, at each of the levels of form, material and meaning.

5 Discussion: Revisiting Gandhi for a Social Design Framework

Gandhi's vision and specific ideas on architecture are co-terminus with larger notions of labor and economy, and emerged from his deep and sustained struggle to overcome economic and social iniquity. Gandhi developed new institutional forms and meanings associated with liberal and democratic spheres [11]. Throughout his lifetime, Gandhi recast and re-configured existing social realities engaging dimensions of social justice, morality, equality and empathy in his own hermeneutic, which advanced a new 'moral' paradigm of problem solving. Balaram

[12] says that Gandhi's approach was not formalist or fixed, but socially motivated. This leads, in our case—to Gandhi's key contribution to social design, with an overlap and interplay between social, environmental and humanitarian domains, which would bring unto the last person, the web of entangled benefits. Trivedi [13] listed few points that can be drawn from Gandhi's integrated vision for India. Some of them are: Karmabhumi (Land of Work and Production), Self-Governance and Self-Rule, Village Self Rule, Critical Industrialization, Decentralization, Sarvodaya (Welfare of All), Equality of all Religions, Women's Empowerment, Removing Untouchability, Providing Basic Education to all etc. Out of this list, Critical Industrialization, Decentralization, Sarvodaya (Welfare of All) can be realised at the first order of production of design. The rest of the virtues like Woman Empowerment, Self-Governance and Self-Rule can become an integral part of the process and labor involved in achieving these virtues.

There has been a widely perceived neglect of the traditional service economy within a largely rural economy in the post-Independence India. To date, formal state institutions, particularly those devoted to science and technology, and the building industry—illustrated here as forms of a political economy, have tended to prioritize the industrial, pushing the informal to the margins; Gupta [14] notes that this asymmetry was only challenged somewhat, by individual scientists and professionals of conscience. It is easy to see that the works of Baker and Hunnarshala lie beyond their immediate temporal, spatial or even social context, and this significant, enduring and relevant aspect anchors scholarly interest. It is the authors' contention that the knowledge and social value of the works of Baker and Hunnarshala need to be assessed through framework ideas that lie at frontier of our understanding of innovation. Gupta [14] has advanced a framework of ideas that incorporates social, ethical, artisanal value within which the enduring social relevance and significance of Baker's, and more recently Hunnarshala's work may be appreciated. This framework identifies innovation across various levels, which yielding significance and depth.

Innovation attaches to a richer understanding of social design as an agent of change, where it is aimed at, embedded in and expresses social imperatives. Newer perspectives acknowledge innovation in the informal economy to be multidimensional [13], and including diverse ecological, cultural, and ethical concerns; which formal economic discourse has long considered 'externalities'. Pointing to the parallel case of agriculture, dominated by "colonial structures of thought where priorities of western journals" assume 'validity', Gupta [14] argues for the effective decolonization of science and technology, to include those where proven results are produced locally, outside the limelight of an institutionalized and industrial culture. It is also pertinent that grassroots innovation is often denigrated and acceptance is not easy to come by; that in view of the prevailing attitudes and there remain considerable obstacles for grassroots innovation at every step from the production to its acceptance by society and mainstreaming of technology. In this light the works of Baker and Hunnarshala achieve the status of 'texts', and loci of discursive practices termed "Alternate Technologies" or a more acceptable, Intermediate Technology. In this way, Baker and Hunnarshala may be considered 'icons' that are 'markers' in a social design, here—architecture. In addition, it may be said that these examples represent reflexive practices that have produced architectures of difference, shaping the discourse.

6 Derivation: Gandhian Framework for Social Design

Both of the practices exhibit a greater model of design, which can be applied through various scales. After visiting through the literature on Social Design, possible Gandhian Ideas on Design, and two practices which inclined towards his Ideas, Hunnarshala and Laurie Baker, we can draw following points for a possible Gandhian Framework of Social Design. Gandhi extended the quest for socially apt solutions, by locating its ambit in the ecosystem of skills, services and goods and the reflexive relationship between process and design solution. Based on the literature, personal experiences, and elite key informants, a few salient features are suggested below.

6.1 Righteous

Design describes the outcome or product, as it does the activities leading to it. The processes and values internal to design influence and shape the product in myriad ways—and are related to the outcome. Gandhi held means to be of importance as the ends—advancing a notion of continuity between spiritual, moral, individual-in-the-world and social planes; when asked for a message he would like to leave for the future, replied—"My life is my message"; unity thus becomes a cornerstone of any framework. A potential Gandhian framework includes notions of 'good' in the path and medium by which things come into existence. The motive in both the case studies is not to create a product, but to cater to the needs of its various stakeholders. In the recent post-riot housing in Muzaffarnagar, Hunnarshala involved a participatory approach to bridge social chasms and empowered the marginalized. Aimed at internally displaced persons, all major decisions were taken up and discussed in the meetings that require mandatory attendance of all stakeholders, including often-marginalized women. Funds were remitted into a bank account in the name of the woman of the household, and the last installment is paid directly to the woman to decorate the house and purchase household goods. This approach was not just inclusive and cautious; it was righteous to the cause of *Sarvodaya*.

6.2 Simple

Gandhi always liked and found simple and sound solutions to complex problems. He rejected Morris Friedman's eight-spoke charkha as he felt that new design would be too complex for him and masses [12]. According to him, existing Charkha was transparent, simple and easily understandable machine. Any addition to it would have added to complexity and illegibility. In most problem solving methods, he used the simplest solutions to solve the most complicated issues. Likewise, the buildings designed by both cases are simple, transparent and utilitarian. Their structures and material are visible and legible to its users. They derive beauty from these values. So, simple and transparent design solutions occupy significance within the framework.

6.3 Empathetic

Gandhi's ideas on empathy have its roots in Ruskinian Ideas [15]. The Gandhian talisman published in the most schools' NCERT textbooks in India advocates thinking about the poorest of poor and marginalized especially those without 'voice'. While both the practices include the communities involved in the making, they also care about the creatures without voices, the environment and the biodiversity. At Hunnarshala's campus, design encourages the birds to nest inside beams. Thatch is used as the building material for most of the units in the complex, becoming home to hundreds of birds. Spaces are designed for the local dogs to facilitate them to rest. The flora too in both, bhunga and hamlet, is natural, organic and self-sustaining. Baker even allowed lichens and moss to freely cover the barren walls in his courtyards. Since, the building materials are eco friendly it causes least harm to nature. Hence, biodiversity is encouraged in this sensitive framework and an empathetic connection with the world is sought to be established.

6.4 Contextual

India possesses rich traditions within a cultural continuum. This is also reflected in the craft and building traditions of her villages. Gandhi was a firm believer in this concept, which is reflected in the built and space making of the Sabarmati Ashram, Ahmedabad, and his own residence. Bhatia [16] noted, Gandhi famously told Baker, "The materials needed to build a house should be acquired from within 5 miles of the site." In their making, Baker involved the local and eco-sensitive material that doesn't burden the larger economy. Hunnarshala did it while constructing bhunga. Both, bhunga and hamlet, the built forms merge with the context;

architectural, urban, economic and ecological. Their buildings look from the place and are identified 'as their own' by its users and promotes the idea of swadeshi.

6.5 Innovative

Gandhi used then innovative moral-social ideas, like Satyagraha and Ahimsa, throughout his lifetime. However, most of these concepts were rooted in India's cultural knowledge systems. Analogously, Hunnarshala and Baker's often used materials and combinative techniques exemplified in the use of Thatch, Mud rolls, Waste wood floors, and Filler slabs with matkas, exhibits innovation rooted in building knowledge systems offering dignity to craft traditions and artisans. Their highly intuitive and creative solving of structural (building) problems such as of spans using pioneering combinative materials and techniques point to innovation that is simultaneously heuristic. With this, the dialogic processes encourage contributions from various persons; artists, architects and artisans. They respond to the pervasive social problems of their times, and rich notions of design attach to their offering creative solutions to this gestalt. Thus, innovation, as exemplified, forms as the integral principle for a Gandhian framework for Social Design.

7 Conclusion

The proposed Gandhian framework of social design has developed over the common ground between the ideas of Gandhi, concepts in social design and innovation, the practices of Baker (COSTFORD) and Hunnarshala. The above points are not distinctly stand alone concepts but entangled with several other ideas. They overlap, share domains and do not have sharp boundaries. The authors hope that this framework can find its context in explaining practices within a spectrum including the traditional fields like architecture, industrial design and emerging fields like service design.

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Closing the Loop: 'Systems Perspective' for the Design of Food Packaging to Facilitate Material Recovery

Amaltas Khan and Puneet Tandon

Abstract Most of the discarded food packaging waste is a result of complex material combination conceived during the design stage. Also, the conventional packaging designs are tough to be recovered in varying end-life situations of packaging. Most of the valuable material resource end-up into landfills in the absence of design practice to facilitate contextual waste management practice. In such circumstances, packaging design to facilitate material recovery by closed-loop recycling is a suitable approach to attain valuable resource recirculation into new forms. In this work, we propose a model for primary food packaging design to facilitate designs with material recovery provision. The model perceives the requirements of the packaging in the form of the open and closed system. The purpose here to provide a guiding framework that would facilitate the design of packaging with the provision of material re-circulation with respect to varying waste management setup(s).

Keywords Closed-loop recycling · Food packaging design · Packaging waste management

1 Introduction

Globally, the increased sales of processed foods have led to growth in production and consumption of packaging materials. Accordingly, the material researchers develop new and suitable packaging to reduce raw material consumption. The food packaging consists of: (i) primary packaging is in close contact with the food product, e.g. PET bottles, sachets, etc.; (ii) secondary packaging is sales and display

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package; and (iii) tertiary packaging is the outermost packaging that facilitates safe handling, bulk storage and distribution of primary and secondary packs. Most of the new Primary Food Packaging (further referred as PFP) are a combination of two or more base materials, e.g. Aluminum (Al) and Polyethylene Terephthalate (PET), so as to attain desired food preservation characteristics along with minimizing the use of raw materials. Tetra pack, laminated boards, and flexible packaging are examples of such multilayered packaging materials that are widely used in food packaging. However, during the end-life stages, these multilayered materials are difficult to be recovered in the absence of suitable material recovery techniques [1]. Especially, in the BRICS (Brazil, Russia, India, China and South Africa) countries, the policy instruments and facilities to support the recovery of such materials are not developed [2]. Also, the available technology to recover these complex materials are at early stage of development, and therefore, could not recover considerable materials into its constituents [3]. As a result, considerable material resources are left unattended and reach the dumpsites. Open incineration and landfilling are some of the viable options that are practiced till date, irrespective of the environmental hazards.

The design phase plays a crucial role in defining the performance of the PFP. The role of a food packaging designer is to identify the requirements of the food and protect it during various interactions of the food-pack life cycle stages. The designed performance of the PFP is as per the expectation until the product-consumption stages. However, during the post-consumption stages, most of the PFP reach the landfills irrespective of the end-life provisions and features in the design of packaging [4, 5]. The unintended disposal of PFP materials in developing and under-developed countries is increasing severely. Surely, there is a lack of collaboration between the design phase and contextual waste management practice.

Both the characteristics, i.e. complex nature of PFP and contextual end-life material recovery practice, play a vital role in defining material recycling rate(s) during the end-life stages. The latest trends in material development for environmental sustainability includes the cyclic use of resources. Closed-loop recycling (further referred as CLR) of materials not only reduce the disposal but also reduce the recurring investment(s) of industries in the raw material [6]. However, the multifaceted requirements make it challenging to develop a PFP with the provision of closed-loop recycling during end-life stages.

This work proposes a packaging design model that is focused on CLR of PFP to enhance the end-life material recovery. Also, provisions to recover such PFP in varying contextual circumstances, especially in the developing countries is considered. We consider the fundamental concept of 'thermodynamic system' to resolve the PFP issues. If critically analyzed in a systems perspective, the packaging acts as a system with the desired input-output to control the food preservation. Accordingly, we have introduced the 'systems' approach in the FPDP so that the quantitative and qualitative requirements of the food can be disintegrated in the form of mass, energy, and information. The model would facilitate the packaging design along with consideration of all the requirements of food-pack life cycle stages in the form of mass, energy, and information. The work also proposes the implementation of CLR approach with respect to the conventional FPDP.

2 Literature Study

The total environmental impacts of the food products are much more as compared to the environmental impacts of the food packaging [7]. As a result, the focus of current PFP design research is more towards reducing the environmental impacts of food and less on the environmental impacts of the packaging.

Recently, numerous policy instruments have been made by the government(s) to control the end-life environmental impacts of the packaging solutions. CEN Standards in the EU, Environmental standards 18601-18606 proposed by ISO, Food Safety, and Standards developed in India, are some of the guidelines proposed by regional, national, and international authority, applicable for packaging industries. Similarly, Sustainable Packaging Alliance (SPA) in Australia and Sustainable Packaging Coalition (SPC) in the USA, are two of the public authority that propose definitions for environmentally sustainable packaging and certify the packaging producers [8]. Most of these public and private regulations can be divided into guidelines (favorable) and instructions (compulsory). Countries like Sweden and Japan show remarkable performance as they have strict regulations for their consumers and producers to follow [9]. Contrarily, the scope for compulsory implementation of packaging standards to various affected regions is outside the reach of design research. There is a need for a design intervention that is independent of the drawbacks of applicable regional regulation(s), such that the standard PFP design could be handled in most of the end-life conditions.

The other way around to resolve this issue, is to provide favorable conditions for packaging producers and consumers to result to CLR food packaging. A few tools, frameworks, and method have been developed to support the designers during the considerations of environmental sustainability aspects in the Food Packaging Design Process (further referred as FPDP). Gronman et al. proposed a framework for FPDP with a purpose to integrate sustainability features in all the stages of the FPDP [10]. Their framework considers the combination of food and pack as a single entity while assisting the packaging designer. Also, the framework takes the support of various assessment methods at different stages of the food-pack life cycle to enhance the sustainability. Svanes et al. presented a methodology where they group the sustainability parameters into five different categories: distribution costs, market acceptance, product protection, environmental sustainability, and user friendliness, with an intention to cover indirect and hidden impacts during FPDP [11]. The existing literature proposes framework and methods that consider the sustainability of the complete life cycle of the PFP. The designer already has numerous multifaceted considerations during the PFP design process and incorporating sustainability aspects may create additional complexity. In contrast, the additional framework should fundamentally incorporate narrow and defined order to reduce mental confusion for the designer.

Most of the existing packaging producers and policy makers have not considered the contextual end-life scenarios in their PFP designs. Also, the existing research work in PFP design lacks the study and implementation of contextual waste management scenario. Collectively, these issues lead to packaging designs that possess various environmental sustainability features, e.g. recycling, less material use, less energy use, reuse, etc., that may not be suitable for a specific end-life stage. It is necessary that a potential PFP design process focus on contextually suitable sustainability feature to constrain the designers and producers to concentrated outcomes.

3 Method

Numerous actors play a vital role in the design of food packaging. These actors are included in the form of inputs and influences in the proposed FPDP. Most importantly, laws and regulations provided by ISO and (Food Safety and Standards Authority of India) FSSAI, India have been studied, and FPDP is accordingly proposed. The role and characteristics of all the important actors have been identified so as to develop the CLR packaging model effectively. We studied the step-by-step generic FPDP followed in industries [10–12], and involved the actors: (i) Various requirements from the market study team provide the generic customer requirements, competitive product details, and business targets; (ii) Public and private regulations control the use of packaging material such that it does not affect the food and the consumer adversely; (iii) Research team search for suitable packaging materials, material production technology, and material vendors; (iv) Based on these requirements, designer develop product concepts and finalize a concept using concept selection tools, e.g. Pugh's concept selection tool, Topsis, etc.; (v) Life-cycle assessment tools are used to study the environmental impacts of the final design; (vi) User study, product simulations are performed to detail the design and final design is send for production, in our FPDP. The condition-specific issues, additionally considered by the designers for the design of special food products, are also included [13]. For example, for the design of ready-to-eat food packaging, the designer has to include microwave features in the packaging materials.

On the other hand, the end-life considerations of the PFP are also important. In the globalization era, a packaging designed in a developed country, manufactured in an under-developed country to be sold in a developing country has varying considerations regarding the packaging life-cycle [14]. A regress literature study was performed to study the waste management context in developing and under-developed nations. Accordingly, fundamental and generic waste management practice have been considered so as to make the packaging material recovery in all probable conditions.

The PFP design model is created, such that the packaging can be disintegrated into its material constituents without many dependencies on the material recovery technology, e.g. mechanical recycling, feedstock recycling, etc. In this way, the chances of material circulation in the form of next product life in expected to increase. Hence, this the PFP design model is developed such that disintegration of materials with minimum technological intervention is possible during the end-life stages.

4 Approach for Closed-Loop Recycling Based Food Packaging

The systems approach is usually applicable in thermodynamics to study the heat and mass transfer regarding a subject. A thermodynamic system consists of (i) a system in focus; (ii) a surrounding that depicts everything else than a system; and (iii) a system boundary that differs the system from the surrounding. If we critically analyze the properties of a packaging, it acts as a barrier that 'control' the input and output, to and from the system. The 'food' preserved inside is the system in focus, and the various external life-cycle conditions comprise the surrounding.

Figure 1 represents the PFP with respect to the thermodynamic system. The food product has a defined set of requirements with respect to the external factors. The primary, secondary and tertiary packaging are designed to provide preservation to food based on the varying surrounding conditions during the packaging life-cycle (further referred as PLC). During the initial stages of PLC, the food-pack combination is stacked and transported in bulk, and the primary packaging is designed to withstand the tough conditions. Similarly, the tertiary packaging has to be attractive, cost-effective, usable, etc., for the customer, and the barrier properties are accordingly designed. Every PFP has a set of requirements that vary specifically to the external conditions and accordingly the barrier properties should be designed.

All the packaging control some of the inputs and outputs to the food preserved inside. For example, in all the designs of milk packaging, it is common that the barrier has to protect the milk from direct sunlight. In all the variety of PFP of milk, it is common that the packaging system enables the milk to be preserved from various external factors, e.g. biological contamination, moisture retention, chemical migration, etc. Also, the packaging barrier has to control the migration of constituents from inside the pack, e.g. spilling of milk, leakage, etc. If we critically analyze the barrier regarding the thermodynamic system, it controls the migration of various forms of 'mass' and 'energy'. The various interaction into and from the barrier, e.g. sunlight, etc., are either a form of energy or mass.

The exploration of system perspective is performed to explore a generic technique to preserve the integrity of the PFP material(s) without affecting the food preservation requirements. Rather than making a conventional PFP combination of complex material combination, here we are progressing to the design of packaging in such a way that all the barrier materials, e.g. mass and energy can be integral during the initial stages of the FPDP. Fundamentally, this approach will provide us a solution that would retain the packaging material in their elementary form and hence could facilitate PFP recycling in a closed-loop.

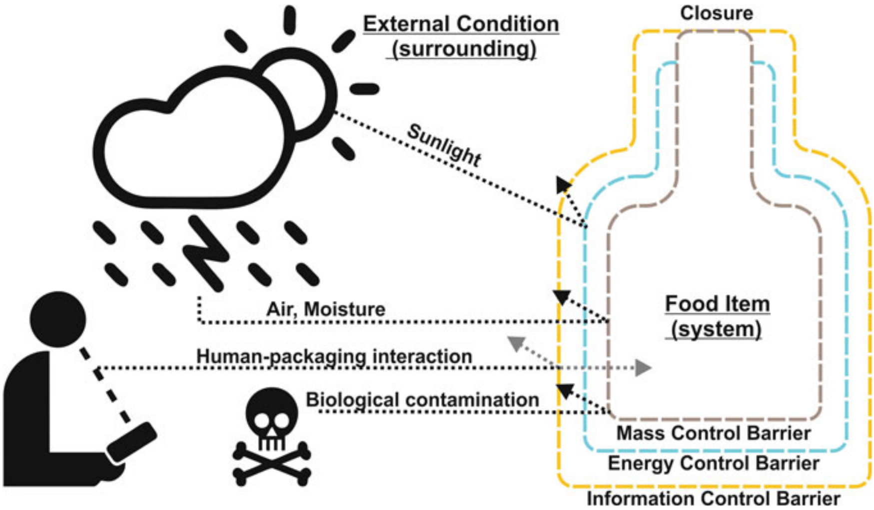

Fig. 1 Representation of primary food packaging in terms of CLR approach

One important entity of the packaging is the various human interactions that cannot be quantified in the form of mass or energy. As shown in Fig. 1, some of the packaging characteristics, e.g. packaging graphics to attract customer, info-graphics for product handling and usage, visual feedback of food content from inside the package, etc., cannot be depicted in the form of mass or energy. These interactive elements are communicated in the form of 'information.' Information connects the sensory channels of the human being to the interactive element of a non-living object. Hence, in the CLR packaging model we are adding 'information' as the third generic property of the packaging barrier.

Summarily, the CLR packaging approach assists in the disintegration of the properties of the packaging barrier into mass, energy, and information. However, it is a tedious process that requires the expertise of the designer in the thermodynamic systems. It is necessary to provide a proper model to implement this approach in the generic FPDP process so that the designer can easily develop the packaging barrier. The next section proposes the model to use the CLR approach in the FPDP.

5 Implementation of Closed-Loop Recycling Based Food Packaging

The designer has to handle a different set of the requirement through the various stages (discussed earlier) of the FPDP. For the designer, it is already challenging to consider various multifaceted requirements to derive a packaging fit for all expectations [11]. It is necessary to merge the CLR approach such that it ease out the conventional FPDP along with fulfilling the set of end-life CLR requirements. Accordingly, the CLR approach applies to the concept generation stage of the FPDP. The designer has to perform the following steps till the concept generation to derive a disintegrative PFP solution.

5.1 *Identification and Categorization of Requirements*

During the initial stage of the CLR model (refer Fig. 2), the designer is expected to categorize the findings provided by the various stakeholders, i.e. market study, economic expectations of producer(s), customer expectations, and government regulations. All actors provide the qualitative and quantitative requirements that are expected from the food-pack combination during the entire life-cycle. It is necessary to categorize the data in the form of food preservation, transportation, customer, economic, regulations, etc.

5.2 *Design Features*

All the expectations from the packaging are necessary to be converted in the form of packaging design features. This step plays an important role in defining the expectations with respect to the packaging barrier, as the collected ‘information’ details are in the form of ‘expectations’ from the food-pack combination. For example, during the customer study for the existing competitive products, the researchers may found that there is an issue regarding the opening of the package.

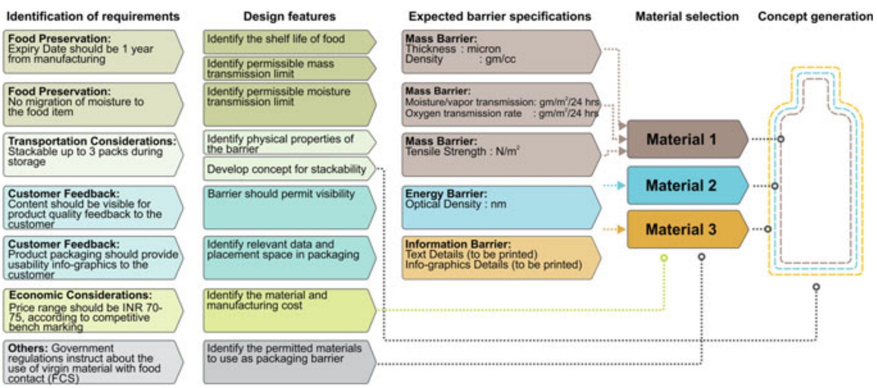

Fig. 2 Stage-wise implementation of CLR model in PFP design process

The designer may either lead to a new form of opening, or infographics to convey the guidelines in order to resolve this issue. In both the cases, provision for proper opening is the 'design feature' of the packaging barrier and has to be accordingly documented. Similarly, other requirements are also required to be documented in the form of 'design features.' This step may be highly dependent on intuition and practice of the design, and, therefore, it is necessary that an experienced designer or a design team handle this process to avoid errors.

5.3 Barrier Specification

The barrier specifications are in the form of quantitative date regarding control of mass, energy, and information to and from the system. For example, the food may have constituents, e.g. preservatives, etc., to preserve its integrity for a defined period and in the event of external contamination, the shelf-life of the preserved food may reduce. In such circumstances, the packaging barrier has to stop every kind of 'mass' to enter the barrier. The 'barrier specification' provide the 'data' of the packaging material that if present, would stop the various form of mass, e.g. moisture, oxygen, etc., to enter inside the packaging. These data can be provided by the material experts and the material vendors. The advantage of this approach is that the designer can quote for 'design' of new material to the material researchers and vendors, with respect to the identified barrier specifications if suitable materials are not available. This specification has to be defined for all layers of packaging barriers, i.e. mass, energy, and information, independently.

5.4 Material Selection

Based on the quantitative details (refer to Fig. 2) of the three independent barrier layers, i.e. mass, energy and information, the designer has to identify suitable materials from the material selection library provided by the material vendors. Special consideration should be given to select materials that are recoverable in cyclic-loop. Also, the recovery technology for selected material should be affordable and maintainable in a various regional waste management context. The contextual waste management practice and policy instruments are also important to foresight the disposal and recovery of the packaging material. The designer may also get two or more materials that provide the barrier properties, and in such case, the designer should choose the material that is most cost effective in manufacturing as well as recovery. Also, the designer should filter out the materials that are not permitted to be used by the applicable regulatory authorities.

5.5 *Concept Generation*

In any design process, some of the data could not be quantified in the form of product details, and the designer has to handle them with their intuition. For example, the packaging form may have to provide multiple features, e.g. stability, volume efficiency, appealing aesthetics, etc., and designer has to identify a standard solution for all cases. These features can be handled during the concept generation stage where one can develop multiple concepts, tradeoff, and choose from the suitable concept for form development. Therefore, the designer should bypass such issues to the concept generation phase. Besides, the designer should compulsorily make provisions of material disintegration during end-life stages of PFP. The best way is to develop material combination, i.e. for all three layers, in a way that they are not adhered to each other and independently serve the purpose. In case there is a requirement to combine all three layers, then the designer should ensure its disintegration into the constituent material(s) during various applicable end-life stages.

The other steps include the testing and detailing of the various functionality criteria of the final concept that can be performed using the conventional FPDP. There are various tools currently being used to access: the life-cycle impact, the usability issues, and environmental impacts. After final stage of detailed design, the final design may go for production.

6 Discussion and Conclusion

In this work, a novel approach to the design of PFP is proposed. The model is derived from the concept of thermodynamic system, where the food packaging is perceived as a 'system boundary' to control the transfer of mass, energy, and information to and from the system. The proposed CLR approach is developed to provide a generic model for the use of packaging material such that they can be recovered for cyclic use during the end-life stages. The emphasis of the model is to fuse the 'system' approach easily in the generic food packaging design process.

There is an obvious need of packaging design intervention to reduce the disposal of packaging material. Also, if the packaging material can be recovered for cyclic use, it can drastically reduce the extraction of raw materials and hence contribute to environmental sustainability. The main findings that lead to this work are that the existing PFP is a combination of two or more materials for which material recovery conditions are not developed. It is most beneficial when most of these renewable materials can be used in close-loop.

This work is limited to the exploration of the CLR model for successful implementation of the design process of food packaging. This work can be elaborated with case studies so as to validate the applicability to derive the suitable packaging. Also, the resultant designs can be applied in contextual waste management practice to test the effectiveness of material recovery. Every method has its benefits and drawbacks, however, with progressing research the benefits should be increased along with reducing the drawbacks. The CLP approach may lead to increase in the cost of packaging per unit of items produced as a result of different packaging layers. However, the direction of packaging material recovery in a closed loop is preferable considering the present and prospected shortage of natural resources. Further, optimization of CLR materials would minimize the cost of production and would make the model more applicable and economically feasible for industries. Also, dedicated technological development to produce CLR food packaging materials would reduce the production cost.

Currently, the disposed PFP is rarely used in other application, even though it has some material properties that remain intact. With CLR model, the resulting designs would invite new actors for the use of post-consumer material. Also, the material production industries may create industrial symbiosis to take back their post-use packaging materials, hence reducing investments in raw materials. Collectively, further research in this directions will surely reduce the cost incurred in packaging, successfully preserve the food, and would lead to substantial reduction in packaging disposal and landfill.

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Sustainability Definitions—An Analysis

Nikhat Waseem and Srinivas Kota

Abstract Every product or system that we consume or use affects our lives and the environment during its production, consumption and disposal. Emissions and wastes are generated which contaminate soil, water and air, the key life support systems on earth. If these support systems will stop functioning in their natural form, then survival and wellbeing of various living things will be endangered. Thus a product or a system should be conceived based on the principles of sustainability. There exist number of definitions on sustainability making it difficult to choose one for application. So in this paper we aim to discuss the definitions of sustainability from different contexts i.e., global and local, temporal and spatial, measurable and non-measurable, and clear and ambiguous. From the analysis we found most of the definitions are global, non-measurable and ambiguous. We need measurable and clear definitions of sustainability to be used in various situations.

Keywords Sustainability · Definitions · Spatial · Temporal · Global · Local · Clear · Ambiguous

1 Introduction

Sustainability can be perceived as an ability to sustain, or a state that can be continued for long at the same level. It is different from conservation, which calls for preserving the ecosystem irrespective of human purpose [1]. The word, 'Sustainable', first appeared in 17th century (in www.etymonline.com) to mean '*bearable*' or '*defensible*', and only from 1965, the current meaning of '*capable of being continued at a certain level*' is being used. During 1970–80 sustainability is used to encompass environmental, economic and social dimensions. In 1987, WCED combined sustainability with development to define sustainable

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development [2]. In 1999, NRC coined the term *sustainability science* and further Kates elaborated sustainability science in his seminal paper [3].

Meadows et al. in [4] cautioned that population growth and natural resource depletion are constraining our future development. This was further stressed recently in [5], since industrial revolution, thriving technological advances, and the material well-being (one dimension of human well-being) has helped in exponential increase of world population. Human creativity which lead to remarkable success in many fields also resulted in many problems such as species extinction, degradation of ecology, and numerous changes in climate, to name a few.

There are numerous definitions of sustainability [6], but still people are making continuous attempts to clarify and aid in various field such as business [7], policy decisions [8], regulatory measures combining businesses and policies, research, and human behavior towards more sustainable configurations. It is important to know the meaning of 'sustainability' in various contexts to evaluate the correctness of deeds [9]. We should define the word holistically and clearly before using the word. Politics influences the way in which our future is going to be and it is important that we manage our environment and resources to ensure human survival and the sustainable progress. We should strive to ensure that we meet the needs of the present without compromising the ability of the future generations to meet their needs. The question is how would these impact product innovation, design, manufacturing and marketing strategies? How about their impact on product development process? The answers need thorough research.

2 Objectives and Methodology

The objective of this study is to know the evolution of research in the field of sustainability and identify the various contexts by conducting a review of definitions of sustainability. Numerous definitions have been proposed till now on sustainability concept. All these definitions are thoroughly analyzed to identify the contexts and the various perspectives based on which these definitions were proposed.

3 Literature Review

The literature search was started by typing "sustainability definition" in google. Then the search was performed by using words such as "sustainability", "sustainability definition" first and then later extended to collect the articles with "sustain" and "sustainable development". The search was performed with the following publishers: Elsevier, Springer, Taylor and Francis, Emerald Group Publishing, Science, PNAS. We got thousands of articles in each of these groups. Careful study was undertaken to collect the relevant articles (which has a definition of any of the above terms).

Different ideas exist about sustainable development in various domains and solutions are developed without understanding the holistic meaning of sustainability across these domains and creating problems across the whole society [10]. What humans choose to sustain within this system depends upon what they value [11]. Understanding the state of the art will help in identifying the gaps for a holistic definition of sustainability.

Elkington, proposed the triangular concept of people, planet and profit [12] for sustainable development. The focus in sustainability is manifold due to varied people having diversified desires over different times, places, and contexts [1]. Sustainability is not understood properly due to inconsistency and ambiguity in definitions and the real meaning is distorted [13]. Defining sustainability has become ultimately a societal choice about what to develop and sustain, and for how long [14]. There is a need to consider objective and subjective interactions among nature, society, and humans [15]. Martens [16] points this as '*multiple interpretations*' and '*uncontrollable*' because of multiple interests, lack of structure and uncertainty in structure. Another issue is the vagueness in the direction of sustainability [17]. Sustainability should be meaningful but, as we require various solutions from it, it will inevitably be vague and disputed [18]. To use sustainability in practice, properties, spatial, temporal aspects and their interrelationships must be further detailed [5].

4 Analysis

4.1 Number of Definitions

We have identified the following perspectives: limits, three pillar, sustain, human welfare, and sustainable development. Here *sustain* and *limits* are taken as different perspectives. The reason being that *limit* implies the threshold of consumption while *sustain* implies the continuation. In the *human welfare* perspective all the definitions talk exclusively about the human well-being like *quality-of-life* or *sustenance of prosperity*. *Sustainable Development* is the classification in which main emphasis is providing guidelines for development in such a way that sustenance is ensured.

The definitions are analyzed from these different perspectives by plotting the number of definitions in each perspective. From Fig. 1, we can see that the highest frequency is of the three pillar concept of sustainability i.e. economy, environment and society. It is followed by human welfare. Definitions on the keyword sustain, sustainable development are followed next. Overall it shows that people are moving towards a more holistic approach, three pillar, rather than only focusing on limits, sustenance. Description of these perspectives used in classification are given in Table 1.

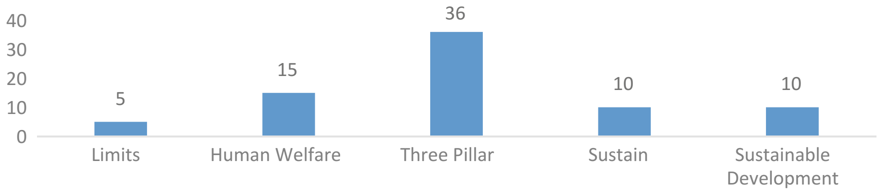

Fig. 1 Definitions in each perspective

Table 1 List of perspectives identified in definitions

Perspectives	Description
Limits	The threshold of consumption
Three pillar	Environment, social and economic
Sustain	To keep in existence, maintain, continue
Human welfare	Ensuring a certain universally acceptable quality of life
Sustainable development	Development approach such that sustainability is ensured

4.2 Chronological Analysis of Definitions

All these different perspective definitions are plotted chronologically (Fig. 2). We can see that definitions based on *three pillar* are spread across the timespan. The interest was on *limits* and *sustainable development* initially and then during 1987–2000, all the perspectives were used. From year 2000 onwards the interest was more on *human welfare* and *sustain*.

4.3 Analysis of Definitions Based on Different Contexts

The following contexts which are described in Table 2 were identified during the analysis and all the definitions were analyzed with respect to these contexts to see which are more prevalent and what these indicate with respect to the implementable solutions for sustainability.

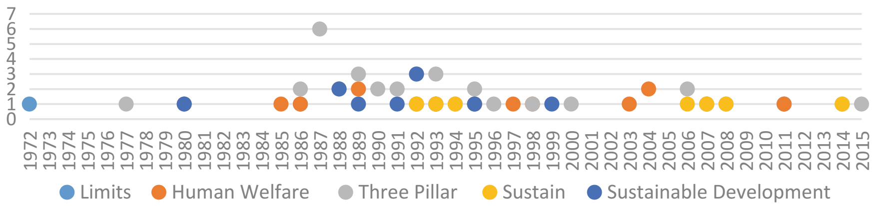

Fig. 2 Arrangement of published definitions (chronologically, 1972–2015)

Table 2 Description of contexts identified during the analysis

Vague: multiple interpretation	Clear: one interpretation
Non-measureable: no evaluation possible to identify the extent of sustainability	Measurable: evaluation possible to identify the extent of sustainability
Local: relating to a particular area	Global: relating to the whole world
Spatial: equity among various regions	Temporal: equity among various times

Table 3 References for definitions in each of the perspective

Perspective	References
Limit	[4, 19–21, 8]
Human welfare	[22–36]
Three pillar	[2, 12, 15, 19, 21, 33, 34, 37–64]
Sustain	[1, 16, 20, 34, 65–70]
Sustainable development	[71–80]

Table 3 consists of the perspectives and the references of the definitions in each of these perspectives. The definitions should be clear, measurable, connect local to global contexts and consider spatial and temporal contexts.

The figures, Figs. 3, 4, 5, 6, and 7 shows the number of definitions that consider different contexts.

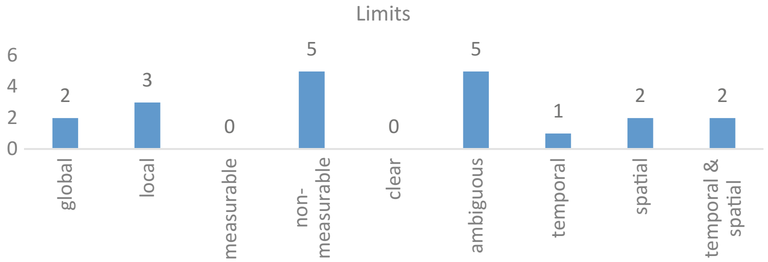

Fig. 3 No. of definitions of *limits* perspective in different contexts

Fig. 4 No. of definitions of *Human welfare* perspective in different contexts

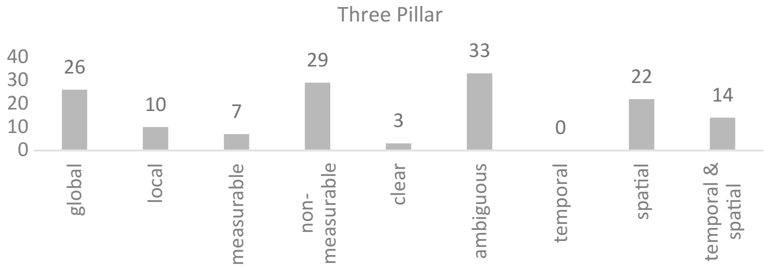

Fig. 5 No. of definitions of *Three Pillar* perspective in different contexts

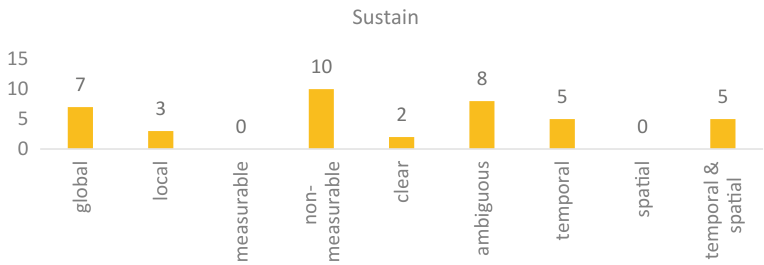

Fig. 6 No. of definitions of *Sustain* perspective in different contexts

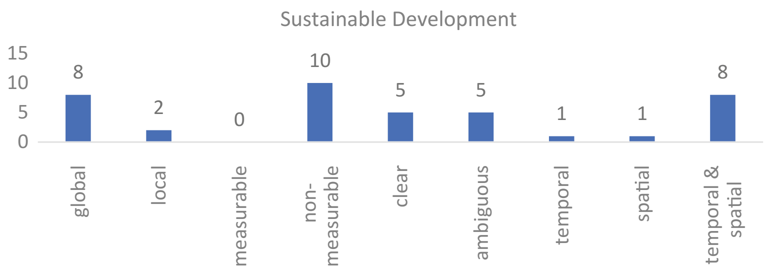

Fig. 7 No. of definitions of *Sustainable Development* perspective in different contexts

It is clear from Fig. 3, that all the definitions in *limits* perspective are non-measurable, ambiguous. More number of definitions are concentrating on local and spatial.

It is evident from Fig. 4, that most of the definitions in *human welfare* perspective are non-measurable, global and considering temporal and spatial equity. Half of the definitions are ambiguous.

It can be inferred from Fig. 5, that most of the definitions in *three pillar* perspective are non-measurable, global, ambiguous and considering spatial equity. Some of the definitions are local and considering spatial and temporal equity.

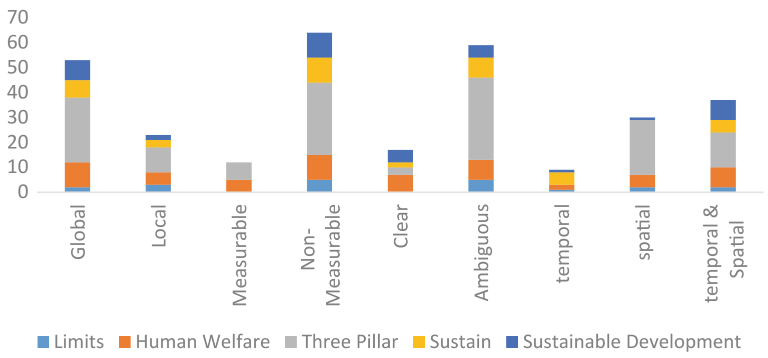

Fig. 8 No. of definitions in all five perspectives in different contexts

It is clear from Fig. 6, that all the definitions in *sustain* perspective are non-measurable, most are global and ambiguous. Half of the definitions are concentrating on temporal or temporal and spatial equity.

From Fig. 7, we can say that all the definitions in *sustainable development* perspective are non-measurable, most are global and considering temporal and spatial equity. Half of the definitions are clear or ambiguous.

From Fig. 8, it is clear that most of the definitions are non-measureable, ambiguous and global in context. Half of the definitions are considering temporal and spatial equity, but without clarity and measurement it will be difficult to implement in real.

4.4 Discussion

The need to analyse various definitions from different perspectives giving the relationship and characterization of sustainability to acquire, apply, transform and recombine knowledge so as to create new knowledge is emphasized from this work. This characterization will help identify the different components of sustainability and these components will help in building the categorization of sustainability indicators once the vast list of indicators are categorized; then appropriate assessment procedure is initiated. In the following articles: [5, 13, 81–84] authors reviewed around ten definitions of the sustainability. These authors have done very illustrative and rational analysis of definitions in isolation (only some categories) or couple of definitions grouped together. So the research presented here is the latest work apart from [18] which was done much earlier. The work presented here analyses the extensive list of the definitions proposed by individuals, organizations and governments in various perspectives. These existing definitions broadly lack the implementation perspective, without that it is very difficult to measure and realize the sustainability.

5 Conclusion

The analysis indicate that most definitions are non-measurable, ambiguous and global in context. This indicate the collective mindset of authors. Most of them are referring to the balance between society, natural capital and economy. This is evident by the highest number of definitions in the category of three pillar. Now the question arises, how that balance will be achieved, when there are different types of societies, natural capital and economies. The dynamics are very complex and has multiple levels of hierarchy and hundreds of classifications. So expressing in few sentences that a particular decision is sustainable is impossible. In future work, definitions in different domains like in transport, agriculture, life sciences etc. will be collected and analyzed to identify any commonality in a hope that it will help in developing generalized measures for sustainability. The developed measures should be insulated from these varied societies, economies and politicization.

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French Education System Organization from Secondary School to University to Prepare Future Engineers to Sustainable Development and Eco-design

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Abstract Today companies must respect environmental laws and standards so the need for skills in the field of sustainable development is increasingly urgent. However, we realize that in terms of education we often propose an awareness approach but it is not enough this concept has to integrate the training curriculum. This is particularly true for engineering education that trains specialists in their field that generally not possess a systemic vision of sustainability. It is a consequence of the fact that their training is limited to a Sustainable Development module too superficial or placed at the end of university. This article presents the French education system organization from secondary school to university to prepare future engineers to SD and eco-design. Our objective is to put in evidence strengths and weaknesses of the French organization of the sustainability development trainings.

Keywords Technology education · Secondary school · Curriculum · Education for sustainable development (ESD) · Eco-design

1 Introduction

Laws like Waste Electrical and Electronic Equipment (WEEE) directive and the Restriction of Hazardous Substances (RoHS) or standards (ISO 14000, 14001) have created a new knowledge' needs in sustainability. So, more and more companies

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search engineers and technicians with sustainable competencies. They are in demand of trained youth in sustainable development and more specifically young people from the training leading to jobs contributing to sustainable development. Aware about this problematic European Union postulated that "*Education for Sustainable Development (ESD) should be central in education and training throughout the life and should, where appropriate, be integrated at all levels and in all aspects of education to better equips citizens to cope with imminent unpredictable problems and to find long-term solutions to these problems in the many different situations in life*" (European Union, 2010/C 327/05). To achieve this goal, France and other European countries have integrated sustainable development concepts in their education systems. So, ESD appears now in curriculum from primary school to university. Understanding of concepts and applications of Sustainable Development (SD) is a long process because SD refers systemic and "ethic" visions of the world which have to be translated in real actions in different disciplinary fields. This long process obliges to have a continuous and progressive approach of SD from primary school to university. This research interrogates ESD and eco-design from primary school to university and relevance of curriculum and associated pedagogies to estimate their efficiency concerning the children and students' "sustainable competencies" development.

In this paper we focus on a particular aspect: SD and eco-design training from secondary school to university. A review of curriculum will be proposed with a view to SD and eco-design training in France to make appear the progressive children and students' evolution of knowledge and skills. Objective is to identify best practices and difficulties in eco-design education to help teachers. Unfortunately, as the paper is limited to 10 pages, work presented here only focuses on organization and programs in France to highlight their complexity, the great number of concepts and their dispersion throughout the different curricula. Propositions to help teachers to adapt their courses in sustainable development and eco-design from secondary school to university will be presented during the conference.

2 Education for Sustainable Development Issues

Many countries (Canada, Japan, USA, etc.) have guaranteed a predominant place to the Education for Sustainable Development (ESD) in the students' school curriculums for several years. Indeed, from their earliest age and throughout their education, students are called to understand environmental, economic and social issues and to be educated in the selection and decision-making [1]. Institutional injunctions indicate that Education for Sustainable Development (ESD) is not a new discipline but an objective beyond disciplines that obliges to create a new organization of existing disciplines [2]. This new organization has to be developed around at least five issues of ESD:

1. Examine links between knowledge and action by encouraging pedagogic activities based on students' action, organized as projects and analyze real situations and/or events. During these activities disciplines which permit to achieve the fixed aims have to be retained and combined. Risk is to be superficial and to stay in logic of common sense because students act more than reflect [3].
2. Identify values and ethics that are fundament of sustainable development: solidarity, open-minded, justice, equality and responsibility. During decision-making and in action these values often generate conflicts with others ones as profit, individual pleasure or preservation of personal acquired.
3. Develop complex thinking. Publications concerning complex thinking often focus on development of a systemic competence. This competence consists to describe a system according to several dimensions or a schema and to use this representation to formulate possible actions [4, 5].
4. Develop capacity to construct the problem on which students have to work. Objectives are to provide students methodologies, approaches and tools to analyze situations that they encounter and to learn to ask critical and reflexives questions in the actual "problematic" world. Reflection is about the choice of the couple problem-situation, of the controversy, debate and insertion in a paradigm.
5. Develop prospective thinking (capacity to imagine not a future but many possible futures). Development of prospective thinking obliges to take into account of the risk society, uncertainty or the concept of prospective [6]. Prospective thinking also returns to the concept of freewill which has to be introduced during students' school curriculum as a necessary dimension to reason the sustainable development and to act.

According to complexity and richness of the five principal issues to be efficient ESD has to be constructed and reflected from primary school to university. Awareness to these issues and concepts has to be developed very early in pupils' school curriculum. Objective is to help students to progressively acquire maturity and a certain depth of reflection about sustainable development. Hereafter this "conceptual" objective, education proposes more "practical" sub-objectives in its school curricula which are often "sustainable development-oriented" and well adapted to historical disciplines. So it's important that student have basic knowledge about ESD. The World Federation for Engineering Organizations indicates: "*it is critical that engineering graduates are equipped with the relevant knowledge and skills to effectively address such challenges in society*" [7]. An answer to these challenges is "*to develop the ability to tackle sustainability before designers enter professional practice that's why it becomes clear that sustainability is a key issue for design education*" [8]. Next section presents the place of ESD and eco-design in French curricula from secondary school to university.

3 ESD and Eco-design in French Secondary School Curricula

The concept of economic, environmental, and societal sustainability is becoming ingrained in the international engineering community. The next generation of engineers will need to be trained in the context of sustainability with an international perspective if they want to participate in solving problems of sustainability at the local and global scale. "*Such complex problems require an integrative approach for solution engineers must be prepared to meet challenges that extend beyond the boundaries of a single discipline. While this perspective ensures that engineers may continue to compete in this period of globalization, we believe that a broader view of engineering education for stewardship and ethical reasons provides a context for engineering students to become leaders in global sustainability*" [9].

3.1 Introduction: ESD from Primary to Secondary Schools

Education for Sustainable Development corresponds to a contemporary insertion of a politic project and a politic vision of the sustainable development in the educational sphere. In the French context, ESD appears in the programs in 2007 as a transversal approach between existing disciplines and not as a new discipline. Programs emphasize the fact that it is necessary "*to create links between disciplinary contributions, by considering a local or global problematic, to help students understanding interdependencies and complexity of the world*". ESD is a part of the national strategy for an ecological transition and sustainable development.

In curricula of primary school and secondary school, ESD is integrated in existing disciplines and scans essentially four poles: biodiversity, evolution of landscapes, management of environments and reduction—reusing—recycling of products. These poles refer to different domains as: agriculture and fishing, trees and forest, climate, energy, wildlife and flora (gardening), patrimony, pollution, relationships between north and south, fair trade, eco-citizenship, health, waste sorting, etc. The aim is to present complexity of the world and different faces of the sustainable development. Study of these poles and domains depends of each professor and it is generally based on an "environmental" approach. In a nutshell, even if sustainability development is about balancing or harmonizing social, environmental and economic dimensions, it is generally presented under the particular focus of environment. As a consequence, primary school provides children eco-gestures to protect environment and are not really help them to be aware to a more global reflection about sustainable development. Pupils of secondary school have often conceptual and blurred vision about the humans' role in modifications of the environment, interdependencies of humans' societies, necessity to make be responsible choices and acts, and about solidarity at world scale. Worse still, few of them have a counterproductive feeling of guilty and powerlessness. In conclusion, it doesn't really exist a continuum of ESD between primary and secondary school and sustainable development concepts are not so much understood by pupils (idem for fives issues of ESD, complex and prospective thinking, systemic vision, etc.). In secondary school, many disciplines address sustainable development concept with their own vision (i.e. without and integrated vision). Concerning engineering sciences SD appears in the eco-design courses. In the next paragraphs the place of eco-design in programs of pre-secondary and secondary school will be analyzed.

3.2 Eco-design Education in Pre-secondary School (Pupils Aged from 11 to 15)

The last decade has seen similar reconfiguration of science and technology curricula in several countries. These curricula encourage: development of competency-based approaches, integrated science and technology, linked increasingly to social questions. In 2008 first notions about sustainable development appear in curriculum of French pre-secondary school. One of these notions in the curriculum is eco-design. Eco-design was an element of technology education and it was seen as a succession of knowledge elements to learn without links between process, properties, use or elimination. For example, materials were studied (physical and mechanical properties only) with the aim of manufacturing because the teaching object was the shaping of materials. Recycling was positioned as a cultural complement; packaging was seen as the culmination (functions of the package) of an object for its marketing. As for materials, aspects associated with the disposal and environmental consequences remained the order of awareness. Today, new frameworks for eco-design trainings try to break disciplinary barriers between sciences and technology in order to encourage pupils to explore the relationships between disciplines while highlighting the sustainable development concepts related to them. Internationally STEM (Science, Technology, Engineering and Mathematics) has contributed since 90s to this new way of education. In France similar program IEST (Integrated Education of Science and Technology) is led in secondary school for pupils aged 12–13. In this way secondary school cycles allow rethink the curricula of training and especially in technology education, where mention is made in the framework established by the Ministry of National Education that lessons must:

- "*Adopt an ethical and responsible behavior,*
- *Develop best practices in the use of communication devices*
- *Analyze the environmental impact of an object and its constituents.*
- *Analyze the life cycle of an object*".

3.3 Eco-design Education in High School (Pupils Aged from 16 to 18)

The situation of the integration of sustainable development concept in the teachings in high school highlights that France adaptations of educational standards were particularly important since 2011. Technological options proposed in 2nd classes (teenagers 15–16 years) are centered on the management of technological project in which pupils have to achieve processes and activities relating to objectives and constraints of sustainable development. After the 2nd class pupils have the opportunity to integrate trainings in industrial engineering sciences that have moved from 7 to 4 options to acquire cross-technology skills in all industrial areas and extensive expertise in a specific field. These options are: "*Technological innovation and eco-design*", "*Information and digital systems*", "*Energy and environment*" and "*Architecture and construction*". Thus, the reform of technological baccalaureate offers pupils access to training in Science and Technology for Industry and Sustainable Development (STI2D). The name for this new diploma and associated options demonstrate an evolution in the organization of technical education or a desire to change old paradigms. Learning is now more focused on the acquisition of a technical culture with a comprehensive approach to multi technology systems. Eco-design in this baccalaureate is presented as a concept that integrates multi-faceted aspects of design and environmental considerations. The objective is to create sustainable solutions that satisfy human needs and desires. In France postulate is that pupils have not only to know how to recycle or separate wastes but have to learn and to understand how they can produce less wastes reduce energy consumption and create a cleaner technology. Nevertheless, even if eco-design could be defined as "*Sustainable solutions are products, services, hybrids or system changes that minimize negative and maximize positive sustainability impacts economic, environmental, social and ethical throughout and beyond the life-cycle of existing products or solutions, while fulfilling acceptable societal demands/needs*" [10], pupils only possess a technical approach of eco-design centered on environmental issues. Economic, social and ethical impacts are generally not studied in high school because they refer to non-technical disciplines and teachers are not trained. Teachers have difficulties to develop technical courses that are not anymore specialized. As a consequence, eco-design courses lead to a global and superficial technical culture integrating the constraints of sustainable development. So, when pupils are going to university they have not a clear vision of sustainable development and eco-design or they have an oriented vision of what it is. It depends also on their specific trainings: 80–85% of pupils at the end of high school are not aware about SD and eco-design because these courses only appear in technical baccalaureate. So some universities often integrate basic courses on SD and eco-design during first-year university level. Other problem is that university is organized according to disciplines, it is not very easy to promote a multidisciplinary approach in courses of SD and achieve the fives issues ESD. In engineering school and companies, problem seems to be different because the need to adopt an integrated approach to respond to ESD issues is often an obvious fact.

4 Eco-design in Universities and Engineering Schools

Universities and engineering schools have to train students who will be decision-makers in companies in which they will have to define and manage strategies integrating sustainable development. So, students may have a global overview of the sustainable development concept. They also have to be able to provide specific answers to environmental, social and/or economic problems depending on their activities in the companies. Universities and engineering school need to bring student curricula with a large vision of sustainable development and technical elements in relation with specificities of each university or school (eco-design, eco-materials, eco-energy, circular economy, etc.). These curricula are often based on standards, methodologies and/or approaches that talk about sustainable management of organizations or products design. Institutional positioning generally seems to be well-adapted in order to permit students construct their own vision of sustainable development. Many universities use for instance the Eco-Management and Audit Scheme (EMAS) developed by European Commission as a start point of a questioning with students about: "what is the signification of sustainable development for a company?". EMAS is a management instrument for companies and other organizations to evaluate, report, and improve their environmental performance [11]. Such instrument is often completed with standards as ISO 14031 (Environmental management, Environmental performance evaluation, Guidelines), ISO 14001 (Environmental management systems, Requirements with guidance for use), ISO 26000 (Guidance on social responsibility), ISO 14040 (Environmental management, Life cycle assessment, Principles and framework) or ISO 14020 (Environmental labels and declarations, General principles). More recently the Agenda 2030 of United Nation and the 17 Sustainable Development Goals (SDGs) that are the heart of the agenda could be also a well-adapted support to introduce "the world we want—applying to all nations and leaving no one behind". These goals are sometimes completed with the Silvius and Schipper's invariant dimensions of sustainability in project management [12] and/or the three facets of the science and engineering meta-discipline from Hokanson and Mihelcic [13, 14]. These dimensions allow providing students a synthetic and systemic vision of SD concept to be adaptable when they will arrive in different companies. Objective of courses is to make appear interdependencies between each goal/dimension to help students to understand complex thinking, prospective thinking and interest to adopt a systemic vision of problems. One way used by university to show interdependencies to students is to adopt a more technical vision of sustainable development in particular with eco-design courses. These courses often refer to the methods and tools used to apply effectively conceptual methodologies and standards in companies (Fig. 1). The different uses of these eco-design

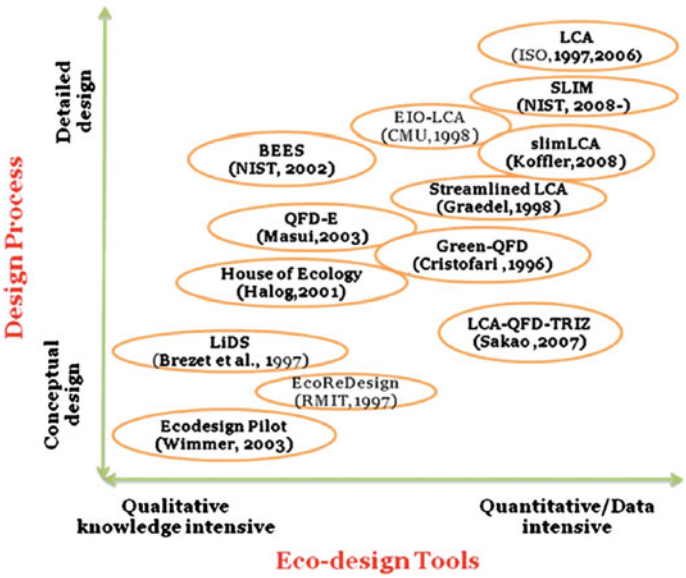

Fig. 1 Map of current eco-design tools [15]

tools create differences and specificities in eco-design training in universities. There is not only one method to speak about eco-design in universities and engineering schools.

5 Synthesis and Conclusion

Table 1 presents a synthesis of ESD and eco-design trainings from pre-secondary school to university. We propose a parallel between institutional programs (column "focus on") and the invariant dimensions of sustainability in project management [12] to show how all dimensions are taught across programs. Table 1 also highlights complexity of the programs and the great number of concepts and their dispersion throughout the different curricula.

Table 1 shows that sustainable development concept is developed in programs but also the fact that it is associated to many different approaches and disciplines. In Table 2, we describe how teachers organize their courses to present SD concept and eco-design to pupils. Multiplicity of the devices is an asset but as there is no coherence between implementation of all of them it is not very easy for pupils and students to understand global objective and interest of such an organization.

Our analysis of ESD and eco-design trainings emphasizes that there is no integration of concepts and disciplines and that there is not a continuum between

Table 1 Invariant dimensions of sustainability in project management and SD concept through curricula from secondary school to university in France

Silvius and Schipper's dimensions of sustainability	Pre-secondary school	High secondary school (S2IT baccalaureate)	University/Engineering School
	Pupils aged from 11 to 15	Pupils aged from 16 to 18	Age 18 to …
	"Focus on"	"Focus on"	"Focus on"
Economic dimension	Fair trade and globalization of exchanges	Globalization of exchanges, circular economy	Globalization of exchanges, circular economy
Social dimension	Responsibility toward environment	Health, fair trade	Health, fair trade, human resources management
Ecological dimension	Wildlife and flora evolutions, biodiversity evolution	Climate, pollution, wastes, recycling and biodiversity	Climate, greenhouse gas, water pollution, wastes, recycling
Time dimension	Human's role in the evolution of the earth (climate, landscape, etc.)	Human's role in the evolution of the earth	Prospective and evolution modeling
Values dimension	Responsibility toward humanity	Responsibility toward humanity	Ethics, social responsibility
Geographical dimension	Evolution of landscapes (mechanism of human's actions on landscapes)	Climate and evolution of landscapes	Influence of projects all around the world
Performance dimension	Resources, energies	***Eco-design***, risk analysis	Prospective, risk analysis, ***eco-design***
Participation dimension	eco-citizenship, awareness to the others	Relationships with subcontractors	Management, communication, ethic
Waste dimension	Production of energy, recycling, water pollution, materials	Production of energy, recycling, materials, eco-design	Eco-management of organization and product
Transparency dimension	Eco-citizenship	Eco-citizenship	Decision-making process, management
Accountability dimension	Eco-citizenship	Eco-citizenship	Decision-making process, risk management
Cultural dimension	Patrimony, political and economic issues in the world	Cultural, political and economic issues in the world	Systemic vision, awareness to the world
Risk (reduction) dimension	Identification of "basic" risks, cause/effect links	Interdependencies between complex phenomenon	Risk management, prospective
Political dimension	Global political organization of the world	Politics in EU	Political sciences, strategic studies

Table 2 Methodologies, tools, documents and projects associated to ESD and eco-design

	Pre-secondary school	High secondary school (S2IT baccalaureate)	University/Engineering School
	Pupils aged from 11 to 15	Pupils aged from 16 to 18	Age 18 to …
Methodologies, tools, documents, standards, etc. (besides institutional elements)	• Real cases studies • Mystery approach • Reading of scientific papers	• Complex real cases studies • Collaborative project • Analysis of scientific papers	• PMBOK • ISO 14… • ISO 26000 • EMAS
Organizations and projects for the class/school (besides institutional elements)	• Small eco-projects in classes and school • Conferences and seminars about SD • Visits of companies • Partnerships with companies, local authorities, associations, etc. • Collaborations with foreign classes • Contest participation	• Collaborations with foreign schools and universities • Complex eco-projects in classes and school • Conferences and seminars about SD, visits of companies • Partnerships with companies and local authorities • Training periods for students in their country and in foreign countries • Systemic modelling approaches and prospective methods • Life Cycle Assessment tools	

pre-secondary school, high school and university. As a consequence, students at the end of the high school are not comfortable with issues of ESD and eco-design:

1. Links between knowledge and action: students provide simple answers to complex problem. Rapidity and facility are often preferred to quality.
2. Values and ethics: institutional injunctions are clear so students know these elements. Worse still, few students have a counterproductive filling of guilty and a feeling of powerlessness.
3. Complex thinking: a great number of students have not systemic competence. They are used to provide simple answers by applying determinist methods.
4. Capacity to construct their own problems: students are used to identify problems to solve. Difficulties are to identify the way to solve problems.
5. Develop prospective thinking: students develop this competence in personal sphere but it seems to be more difficult in the sphere of education.

As competencies associated to SD concept and eco-design are not controlled by neo-students, university's curricula have to integrate these issues since the first year of bachelor. We will complete our proposition with a framework to integrate these issues in university's curricula and we propose a comparative analysis between European, Anglo-Saxon [13, 14] and Asian [16] theoretical frameworks in the field of ESD.

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Disassembly for Redesign

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Abstract The paper proposes to change the way to improve a product by switching the DfD approach (Design for Disassembly) into DfR (Disassembly for Redesign). The concept is to disassemble a product by keeping the just necessary parts that achieve the basic service, the product being still in operation. The disassembly procedure (tasks, tools, duration, resulting parts, …) is recorded in order to express how much frugal the product is. The frugality index measures the difference between the product before and after the disassembly procedure, it consequently expresses the energy to spend to innovate in a more responsible way. The methodology is supported by an example on an EEE product. A discussion is finally engaged to present the limits and the perspectives of the approach.

Keyword DfX · Disassembly · Eco-design · Frugal

1 Introduction

Companies must continuously redesign their products to be more competitive to face the challenge of the worldwide economy. They consequently have to innovate by adopting incremental or disruptive redesign strategies. In order to accompany this trend, methodologies and tools have been developed to help designers in their design process, some of them are known as DfX (Design for X). DfX refers to the use of a formal methodology to optimize a specific aspect of a design that is proactively included in the product development phase. The X represents the areas of focus, as for Design for Manufacturing, Design for Assembly, Design for Disassembly, etc. [1]. DfX is one of the most effective approaches to implementing concurrent engineering [2].

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The choice of a DfX depends on internal or external factors to the company. Internal factors can be due to a continuous improvement process to increase the quality of the products, or to decrease the expenses to improve the value of the products. This situation is not conducive to disruptive innovation because the motivations are not incentive, the company just can expect incremental innovation. Conversely, external pressures can have a positive effect on the design process in terms of creativity. The factors can be: competitors, new directives or standards, supply risks of resources, market changes, client's complaint, environmental issues. The two first factors, competitors, directives and standards, are general considerations which occur continuously, the risks can be considered as minor. On the other side, client's complaint is a critical situation if the company's turnover especially depends on this client. Supply risks can be as well critical if the combination of the following factors arises: lack of substitutes, low recycling rates, high concentration of producing countries (primary production) such as China, which produces 97% of rare earth. In the case of a major risk, companies have to force the creativity to innovate. Finally, environmental issues are now considered as the main factors influencing the organizational and technological change in companies [3]. Among these factors, we can mention the environmental directives (REACH, RoHS, WEEE, etc.), increasing costs of fossil energies, depletion of resources, etc.

From these observations, new DfX have been consequently developed to move towards a more sustainable strategy. Subsequent to Design for Disassembly, Design for Recycling (DfR) [4] consists in designing products so that the components can be cost-effectively easily replaced, reused and/or recycled in many sectors [5, 6]. DfR should be the best approach for a recycling strategy, but most of the time the company is not directly involved in the recycling process. Gries [7] specifies that the difficulty, as with any "Design for X" (e.g. Disassembly), is that designers are rarely directly involved in any activity that the "X" represents. Furthermore, a company can pay an ecological contribution to develop the recycling sector imposed by a government but this doesn't make it compulsory to design recyclable products. So it is more comfortable for a company to simply pay rather than disrupt its procedure, processes, skills, stakeholders, for environmental reasons. Even if a company makes some efforts to design for recycling, this doesn't mean that the real existence of the components/materials is questioned, the company can just look for an optimal disassembly algorithm [8–10].

Unlike cautious behavior of some companies to deal with environmental issues, new approaches based on frugal considerations recently appear in Base of Pyramid markets and developing economies [11]. Many examples coming from India, Africa and other countries propose products that perfectly fit with customers resources, and consequently with environmental considerations [12]. Frugal engineering definitely changes the design paradigm by breaking the traditional R&D principles. The quote "*Necessity is mother of innovation*" could summarize the philosophy of frugal engineering. This challenges the designer who has to rethink the product in its cultural, social, economical and environmental context of usage by focusing on the basic service and by obscuring all fancy functions [13].

In order to explore this trend, a new approach is proposed by facing Design for Disassembly in relation to the frugal engineering concept. The approach is first detailed by describing the means, the procedure and the metric to express the frugality index of a product. Then, an application on an EEE product, a Brother fax copy machine is presented. Based on the results, a discussion is finally engaged to express some limits, such as the role of the operator in the disassembly process, the repeatability of the process or the evolution of the metric.

2 Disassembly Reasoning

2.1 Framework and Objective

The disassembly process of a product is a voluntary activity performed by an actor for a specific reason, and its efficiency is strongly determinated by the design of the product. Based on the multiple roles taken by the actor, different scenarios of the disassembly process can be identified, they are summarized in Table 1.

The table identifies six principal roles: user, maintenance operator, designer, LCA expert, recycling operator, competitor. For the user, his responsibility is engaged if the warranty is exceeded. If not, the producer can authorize the user to change the failed component or the consumable. If the user is not allowed to repair, the maintenance operator is asked to quickly fix the problem by disassembling the product to repair or change the failed component. For the recycling operator, depending on the sector, parts are recovered to give a second life but most of the time the product is dismantled, the materials are collected and recycled. For the designer, if an important customer complaints on the product, his responsibility is to recall the products, to disassembly them and to fix the problem. Concerning the LCA expert, the environmental assessment is mostly made by a consulting firm, in this case a global disassembly of the product is required to identify all components and materials. For economic intelligence, if a competitive product monopolizes a market, a competitor can purchase and disassemble the product to understand and to copy its technology.

Based on these scenarios, only three of them could be used to engage the redesign of a product. The first case concerns the product recall, only incremental innovation could be considered to fix the problem by minimizing the expenditures. In the second case, the eco-design of products can be done with a better recycling. The last case concerns economic intelligence, a company should innovate with a disruptive technology to surpass an important competitor.

As a result, the scenarios show that a disassembly process is often used by default to address a technological problem or to increase the recyclability rate. Except in the case of economic intelligence, we hypothesize that a disassembly procedure can give other opportunities to innovate. For this, a new perspective can be offered on the basis of what is being developed for BoP markets. Some strategies

Table 1 Disassembly scenarios

Actor	Cause	Objective	Context
User	Failed product	Repair or buy spare parts to increase service life	Out of warranty, don't need specific skill
	Lack of consumable	Add new consumable; increase service life	Normal usage with consumable
	Old fashioned appearance	Change only visible parts	Market/social network pressure
Maintenance operator	Failed product	Repair or buy spare parts to increase service life	Under warranty or not, need specific skills
Designer	Complaint of customer; product recall	Repair to increase reliability; global product improvement	External pressure, critical situation
	Continuous improvement	Global product improvement	Internal pressure, non critical situation
	Standards, directives	Improvement of the environmental impacts	Internal/external environmental policy
LCA expert	Life cycle inventory (LCI)	Ecolabel, green communication	Environmental marketing
Recycling operator	Rejected product by customer	Recovering of parts and/or materials	Professional Recycling sector
	Failed product	Repair or buy spare parts to offer second life	Social recycling
Competitor	Economic intelligence	Reverse engineering to understand the technology of a competitive product	Industrial competition

coming from Asia or Africa propose to go forward through innovation with a philosophy based on frugality. The scientific literature often defines frugality as the ability to do more with less [13]. Frugal engineering should be an opportunity to experiment new strategies because companies have to face a worldwide crisis due to environmental issues, such as the cost of energies or the depletion of resources. They are warning signals to producers to engage new design reasoning based on frugal considerations.

In order to support this trend, a new disassembly procedure is proposed as a support tool for a frugal redesign. The procedure is called "living product autopsy", it consists in disassembling a product by only keeping the essential parts of the components to achieve the fundamental service of the product. The proposal is an attempt to give a kind of technological shock to the designer, to change its redesign reasoning.

2.2 Living Product Autopsy

Autopsy platform. The living product autopsy is inspired from medical autopsy workspace. Four mobile units constitute the workspace: a lift table, a mobile service tools, a components storage system, an audio-video recording system. The ergonomic lift table locates the product at the right position for the operator who makes the disassembly, in our case the lift table can carry maximum 150 kg. A set of tools is available to perform the disassembly, it contains standard tools (screwdrivers, wrench, etc.) and specific tools (endoscope, desoldering unit, …). The mobile storage system contains the useless components removed from the product during the autopsy. The mobile audio-video recording system is a 360° video recorder (Gyroptic) with led lights located at the end of a suspended rotating arm. The operator simply moves the video recorder in front of the table, the system captures the environment at 360° during the autopsy. The recording system can be used in real-time under the observation of offsite operators, or for a post-analysis.

Autopsy procedure. The autopsy is made of four fundamental phases performed by an operator called "investigator":

- The first phase consists in observing the usage of the product in order to identify user's activities that influence the functioning of the product. For example, when a user reloads paper in a copy machine, a sound is emitted and the message "paper tray open" appears on the control panel. Consequently, the investigator will look for presence sensor and will shunt it, assuming he wants to remove the tray and to continue the autopsy,
- The second phase consists in defining the functional unit representing the fundamental service of the product, it will be used to check the functioning of the product during the disassembly,
- The third phase consists in performing the activities of the living product autopsy, (detailed below),
- The fourth phase consists in comparing the product before and after the autopsy to identify its structural frugality.
- Based on the results, new proposals can be made to redesign the product depending on the degree of innovation the company expects.

Autopsy activities. Before to physically engage the autopsy (third phase), the investigator must comply with safety instructions. The product can be under voltage (if EEE), it could have moving parts or other dangerous components (laser, hot component, etc.). If a user's guide exists, the investigator should verify the advice, and should take all necessary protections (gloves, glasses, …). When the safety conditions are respected, the investigator can engage the living product autopsy that consists in six steps:

- Identify: the investigator uses his own senses (sight, touch) to detect connecting components and/or structural discontinuity [14]. The fasteners are common entities used to assemble at least two parts, they can be: screw, bolt, nut, circlips, rivet, pin, elastic, clamping collar, etc. The structural discontinuity corresponds to a geometric difference between continuous surfaces: change of form (groove, hole, excrescence, etc.), change of colors, roughness, gradient of temperature, etc. In terms of feedback, the investigator verbalizes his thoughts and actions that are recorded by the audio-video recording system,

- Verify: the investigator decides if a component (or a set of components) can be removed or not, depending on its participation in the achievement of the functional unit;
- Associate: the investigator decides what kind of tool(s) must be used to dismantle the component,
- Disassemble: the investigator separates the component with the tool(s) from the rest of the product, and stores it,
- Test: the investigator verifies if the product still works; reconnects the component if not,
- Repeat: the investigator restarts the process as the functional unit is not affected.

Note that the procedure can stop if a security risk may occur. Remember that the disassembly is performed while keeping the product in operation.

Frugality index. The last phase of the autopsy consists in defining the structural frugality index of the product. Assessing frugality is not an absolute science, but it does provide a picture of issues that are driving the access to more ecological product. To be eligible frugal, a product must contain the just necessary quantity of components (or materials) to achieve the functional unit. An aggravating factor is applied to consider a bad recycling rate of the removed parts.

The just necessary quantity of materials (Q) is calculated as the weight of the living product after the autopsy (W_a) divided by the weight before the autopsy (W_b).

$$Q = W_a/W_b \tag{1}$$

The aggravating factor (A) is calculated as the rate of the removed parts that are not recyclable. The weight of the recyclable parts is denoted W_r.

$$A = (W_b - W_a - W_r)/W_b \tag{2}$$

The two previous elements are put together to create the structural frugality index denoted ϕ.

$$\phi = W_a(W_a + W_r)/\mathrm{W}_b^2 \tag{3}$$

The equation of the structural frugality index is a simplified version of the frugality. Additional factors could be applied to express the possibility to improve the parts of the living product, especially if some of them are independent in terms of functionality. The case study will give some proposals.

3 Case Study

3.1 Context and Objective

The sector of electric and electronic equipment (EEE) is a growing market, the technology quickly changes, the products are continuously renewed [15], they are small enough and easily available for a case study. For our concern, the living product autopsy is applied on a Brother Fax-copy machine Model 2820 used at the university for years (Fig. 1). The machine is operational but the fax is no longer used (replaced by email) and the printer is too slow compared to current user's demand. The specifications of the machine are: made in China, 220–240 V, class 1 laser product, a weight of 8174 g, dimensions are 374 mm × 374 mm × 262 mm, the paper tray contains a maximum of 250 A4, ink cartridge is removable. Note that the investigator doesn't have any knowledge on the copy machine technology before engaging the autopsy.

The objective is to disassemble the product just before the funcational unit is affected. In the present case, the study focuses on the copy service, the fax service being no longer used.

3.2 Application of the Living Product Autopsy

The procedure has been applied on the Brother machine during 4 h, it has been stopped when the investigator considered that additional disassembly activities would affect the functional unit. The feedback of the four phases is:

- Usage observation: the investigator noted that when the paper tray is removed, the machine beeps and gives a message on the control panel. Consequently, a presence sensor must be found during the autopsy and shunted if necessary. Same situation when the back cover is removed to fix a paper jam, or when the cartridge is removed.
- Functional unit: make one copy of an A4 document,

Fig. 1 Product to autopsy: Brother Fax copy Model 2820

- Activities of the living product autopsy: in the first moments of the autopsy, basic components have been removed, as for the paper tray. For this, an adhesive has been used to shunt the presence sensor (mechanical switch). Five other presence sensors have been found: one mechanical sensor, two electronic sensors integrated in electronic cards, and two optical sensors. The presence of screws permitted to quickly guide the investigator towards disassembly possibilities. The touch also permitted to detect hidden screws under a textile glued on a plastic component, and after taking off the textile the screws have been removed to separate components. The endoscope has been used three times to confirm the presence of optical and mechanical presence sensors, some of them has been shunted.
- Structural frugality index: data have been collected during the autopsy, they are: type of material and weight of the removed components, the tools (screwdriver, endoscope, scissors, clamp, adhesive, etc.). Based on the collected data, the detail of the frugality calculation is given below.

After the autopsy (Fig. 2), the resulting living product contains six subsets: the control panel, other electronic cards, scanner, cartridge, laser, power supply. For the removed parts, six groups of parts/materials can be listed: a speaker, a fan, acrylonitrile butadiene styrene (ABS) parts, metal sheet, plastic sheets, fasteners. Table 2 lists the categories of materials/subsets with their respective weight.

The weight of the initial product is 8178 g, it becomes 5461 gr after the autopsy. Consequently, it contains 33.2% of useless parts based on the removed components/materials representing 2717 g. The removed parts in ABS represents 86.0%, essentially distibuted in the paper tray (388 g) and the hull parts (2329 g). The recycling rate of the removed parts is estimated at 94.8%. The structural frugality of the product is estimated at 65.4%, its analysis is undertaken below. General data on the recycling of EEE can be found in [16].

Fig. 2 Removed parts; living product after autopsy

Table 2 Autopsy results

Removed parts		Final living product	
Components/materials	Weight (g)	Subsets	Weight (g)
Speaker	62	Control panel	270
Fan	63	Other electronic cards	290
ABS (paper tray, hull)	2338	Scanner	515
Metal sheet	181	Cartridge	990
Plastic sheets	14	Laser	2600
Connectors (screws, …)	59	Power supply	796
	2717		5461

3.3 Discussion

The living product autopsy is an attempt to analyse a product by identifying the essential service achieved with the just necessary technology. The procedure has some limits we propose to explore.

First, the role of the investigator is important and can influence the procedure. If he knows the technology, he already can propose specific actions such as the shunting of sensors, the activities are consequently shortened and the feedback (verbalization of actions and decisions) could be censored. To understand his influence, a comparative study can be done by analyzing the activities of an investigator aware of the technology and another who doesn't know. Moreover, in order to test the repeatability of the procedure, two autopsies can be done in parallel on the same product with two investigators having the same knowledge on the product. The objective will be to assess the similarities of the final product, and the differences of the disassembly activities (decisions, tools, duration).

Second, in the case study, the investigator didn't stop the autopsy at it extreme level. The cover of the control panel could be separate in order to view the buttons, but he chose to keep it in order to simplify its use. Moreover, he could remove other parts of the frame holding the cartridge, but the procedure could damage the electronic cards. Some uncertainties could therefore be taken into account for the calculation of the structural frugality index.

Third, the metric to measure the structural frugality is a first attempt to quantify how much a product contains useless components and how much the design contains recyclable materials. Additional parameters could be integrated, such as the amount of recycled materials used in the product. But in this case, the investigator should have the complete nomenclature of the product because he cannot imagine the components inside the rest of the living product.

Fourth, in order to validate the autopsy procedure in long term, a comparative analysis must be engaged with others redesign procedures. Its efficiency can only be proved if the results can be transferred, future work will be undertaken in this direction to highlight changing in design practices.

Finally, when the autopsy is done, the investigator can only see the just necessary technology used to achieve the functional unit. This final configuration of the product doesn't give information on its potential redesign, it just inform on how complex or useless the removed components are. We could expect that this procedure could cause a kind of intellectual questioning concerning the way to design the product, and could open new opportunities for alternative design. In the case study, the final state of the fax-copy machine shows that it can be broken down into five modules, each of them achieving a specific function. A global physical reorganization can be suggested for these modules, such as the use of a physical removable module of the control panel which can be quickly upgraded depending on the changes of ICT [17]. In regards to the rest of the product (the removed parts), the designer is now freed from the technology and can propose new possibilities to improve the frugality index. Note that if the designer keeps the technology of the useful parts, the redesign is incremental but the border to a disruptive approach could be easily crossed. This part is not covered in our study, but it will be next investigated with designers of a local company.

4 Conclusion

The paper shows that Design for disassembly (DfD) can be used for different purposes, depending on the actors engaged in the process. Unfortunately, despite the different possible scenarios, this technique is not encouraged for innovation. Most of the time, the method is studied in a limited way, such as algorithms to find the best way to optimize the duration and the disassembly costs. In order to offer new perspectives, the disassembly process is hijacked to help designer to innovate in a more responsible way. A new procedure called "living product autopsy" is proposed. It consists in removing parts of a product that do not participate at the achievement of the fundamental service, the product being still in operation. The new disassembly process is inspired from a medical autopsy, it records all information and decisions taken during the disassembly protocol performed by an operator named investigator. At the end of the autopsy, an analysis expresses how frugal the product is. The frugality index depends on the differences between the initial state of the product (before disassembly) and its final state (after disassembly) in terms of weight and percentage of recyclable materials. By applying the methodology on a fax-copy machine, the autopsy reveals that 33% in weight of the product is affected to the removed components that are therefore useless. The rest of the product can be the starting point to find clever solutions to increase the frugality index.

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A Sustainable, Eco-friendly Charge Storage Device from Bio-charred Jute: An Innovative Strategy to Empower the Jute Farmers of India

Amarish Dubey, Deepu Philip and Mainak Das

Abstract Jute is a major fiber crop of India, which is used extensively as packaging material. Recently, jute industry is facing stiff challenges from synthetic fibers and plastics; resulting in major decline in the revenue of jute growers. This necessitates the quest for alternative and innovative design avenues where jute can be used to fulfill the need of the jute growers. This paper describes one such alternative where a sustainable, eco-friendly charge storage device is developed using bio-charred jute; thereby opening new avenues for jute industry in the energy storage sector. Implementing similar innovative strategies at national level could revive the interest in jute farming among Indian jute growers and other cash crop growers.

Keywords Jute · Bio-charring · Charge storage device · Design for sustainability · Eco friendly design

1 Introduction

Jute is an important fibre crop of India. Raw jute and manufactured goods made from jute contribute to foreign exchange to the tune of INR 3000 million per annum. Presently, Jute fibre is extensively used for manufacturing gunny cloths, gunny bags and other packaging materials for storing and transporting agricultural commodities. Jute stalks that are stripped of fibre also find its application as fuel and also a source of gun powder charcoal. Several paper mills produce coarser paper using jute [1]. However, plastic and synthetic fibres have encroached into the

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packaging industry; thereby ousting jute products from the market at a rapid pace. For safe guarding the interest of jute farmers, new and innovative avenues of applications of jute needs to be identified. Here, we present one such innovative application of jute fibre viz., a sustainable manufacturing route (bio-charring) through which jute fibre can be used to generate high quality 'hollow carbon tubes'. Such hollow tubes are further used as raw material for developing charge storage devices. Such charge storage devices become eco-friendly and also is bio-degradable due to its natural origin, thereby opening the new era of designing sustainable charge storage devices. Subsequent sections of this paper describe the design and development of jute based energy storage devices.

2 Generation of 'High Quality Hollow Carbon Tube' from Jute to Realize Sustainable 'Charge Storage Device'

2.1 Bio-charring of Jute to Generate 'High Quality Hollow Carbon Tube'

Bio-charring is the process of burning organic material in absence of oxygen. It is already demonstrated that bio-charring of silk cocoon membrane results in heavily nitrogen doped graphene like sheets, which find its application in supercapacitor and as magnetic-fluorophore material [2–4]. A similar strategy is followed in this work, where bio-charring of Jute resulted in the generation of 'high quality hollow carbon tubes'. In short the process is as follows.

The raw jute fibers are cut into small pieces and kept in a crucible for bio-charring in an inert furnace at a fixed temperature. The inert environment is maintained by purging argon or nitrogen gas inside the furnace. The heat increment of the furnace was set at the rate of 5 °C/min, till the set temperature was reached. Bio-charring was performed for 4 h; and then the bio-charred sample was allowed to cool down in the same inert condition [5]. Figure 1 depicts the entire process schematically. The bio-charred jute was washed with multiple rinsing of acetone. These hollow carbon tubes have significantly high volume as well as surface area.

2.2 Outlining the Route of Developing Charge Storage Devices from Hollow Carbon Tube Derived from Jute

The researchers are attempting to pattern carbon nano structures for batteries and supercapacitors application, since these structure are having very high surface area-volume ratio for storing electrolytic ions. Interesting in the case of jute, it is possible to obtain hollow cylinders at nano scale, so as to increase the surface area

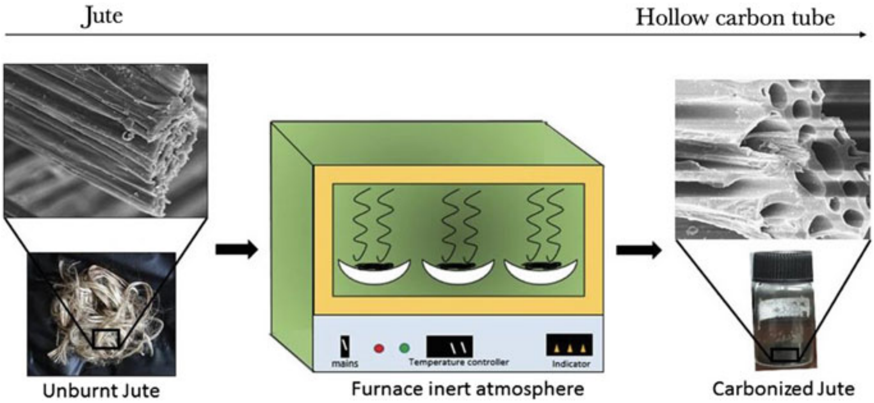

Fig. 1 Bio-charring of jute to generate 'high quality hollow carbon tube'. From *left* to *right*, Unburnt jute and the scanning electron microscope (SEM) image of unburnt jute. Temperature controlled furnace an inert environment. In the *right panel*, bio charred jute with their SEM image showing hollow cylinders

t-volume ration many fold higher. Further we investigated that carbonized jute or bio-charred jute is a high quality raw material for charge storage device development. In Fig. 2, the overall process for developing a simple 'bi-functional charge storage device from hollow carbon tube' derived from jute has been pictorially depicted. Here, we have taken two graphite sheets to function as a current collector. The bio-charred jute (jute carbon) is dissolved in isopropyl alcohol (with 10% Nefion) and sprayed uniformly on the two graphite sheets of 3 cm^2 area. Poly-vinyl alcohol (PVA) and 1 M phosphoric acid (H_3PO_4) gel is used as electrolyte and placed on the jute carbon coated graphite sheets. Then the two graphite sheets are sandwiched by placing a cellulose separator between them. This resulted in the a complete single unit of charge storage unit. Further such multiple units are attached in series to generate sufficient power to operate devices like light emitting diode and low power DC fans. A similar methodology was used elsewhere for developing charge storage device from iron pyrite [4]. Even, we can make flexible charge device by sticking thin graphite layer as a current collector on commercial cello tape and the remaining process remains the same as describe above.

2.3 *Critical Temperature Is 400 °C for Obtaining Hollow Carbon Tube from Jute Bio-charring*

The challenging question was, at what temperature, jute is needed to be bio-charred so that maximum yield of hollow tube like structures is obtained. Initially, we carbonised the jute at different temperature viz., 300, 400 and 500 °C. We examined the structures obtained from bio-charring at different temperatures by SEM

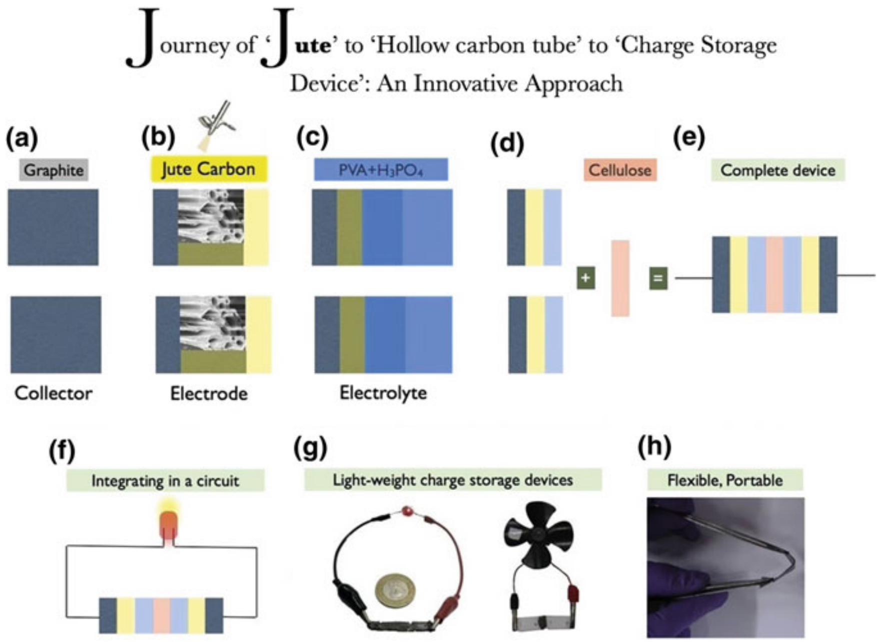

Fig. 2 Development of bi-functional charge storage device from bio-charred jute. **a** Two symmetrical graphite sheets for current collector. **b** Bio-charred jute coated on the both graphite sheets for working as an electrode. **c** PVA + H_3PO_4 gel electrolyte placed on electrode. **d** Cellulose separator sandwiched between the electrodes. **e** Complete single unit of charge storage device. **f** Diagrammatic single unit connected with the LED. **g** Charge storage device size comparison with Indian coin; two same device connected in series for glowing LED and other two to run DC motor fan. **h** Flexible property of charge storage device

imaging, and verified material storage property by cyclic voltammetry (CV). We used Carl Zeiss EV 018 for SEM imaging and Basi Cell Stand C3 for cyclic voltammetry (CV). The unique morphology of hollow carbon tube was obtained while bio-charring the jute at 400 °C. In Fig. 3, we observe that the 400 °C carbonised jute has proper hollow tube structures, as compare to 300 and 500 °C carbonised jute. The 300 °C carbonised jute is having thicker wall (similar to partially burnt carbon) and 500 °C carbonised jute showed a shrunk morphology (similar to over burnt carbon). At 400 °C, carbonised jute offers the unique hollow structure morphology. We verified it by electrochemical characterisation. We made electrode and symmetrical charge storage device of 300, 400 and 500 °C bio-charred Jute. In Fig. 4, a comparative electrochemical characterization (cyclic voltammetry) of bio-charred jute at 300, 400 and 500 °C has been shown. We have shown in Fig. 4a, the comparison of electrodes and in Fig. 4b the comparison of symmetrical device at 300 mv/s scan rate with 1 M H_3PO_4 electrolyte. We observed that maximum current density and area was observed from 400 °C bio-charred jute (red trace) electrode. In comparison with 300 and 500 °C samples, the 400 °C sample exhibit the optimal electrochemical properties. Further electrochemical properties were investigated for the 400 °C carbonised jute. We did CV from 5 to 500 mv/s for both electrode and unit device with 1M H_3PO_4 electrolyte. We observed that CV follows the ideal supercapacitor property as it showed a rectangular shape. As we increased the scan rate, the area covered under the CV trace increased (Fig. 4c, d) while the specific capacitance decreased. In Fig. 4d for unit device, at 300 mv/s scan rate of CV, we got a current density of 9 mAmp/cm^2 and specific capacitance of approximately 200 F/g that shows a quite significant capacitance and current value.

2.4 Characteristics of 400 °C Carbonised Jute

400 °C bio-charred, was further studied for all further investigations. XRD (Panalytical XPert) and FTIR was used to characterized the bio-charred jute. In XRD trace, we observed a pronounce broad peak at $2\Theta = 26.4^{o}$ for (002) plane, which indicate that it contains good graphitic structure (in Fig. 5c) [6].

Figure 5d shows the FT-IR spectra (Bruker Fourier transform infrared spectrometer; Vector 22 model). Spectra was taken at 400–4000 cm^{-1} range with a resolution of 4 cm^{-1}. We observed a broad sharp peak at 3409 cm^{-1} for –OH

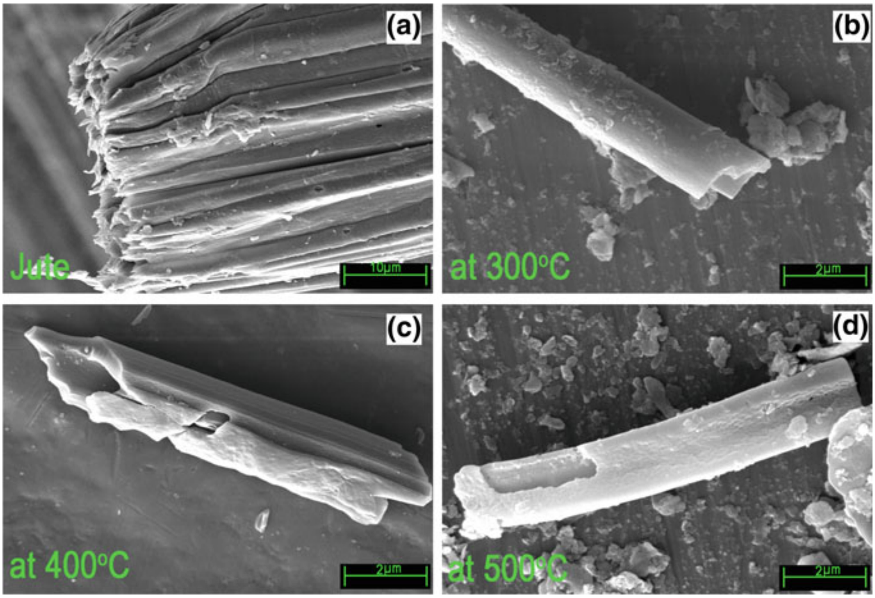

Fig. 3 Comparing the SEM images of bio-charred jute at different temperature. **a** Unburned jute image. **b** SEM image after bio-charring at 300 °C. **c** SEM image after bio-charring at 400 °C (perfect hollow tube as compared to others). **d** SEM image after bio-charring at 500 °C

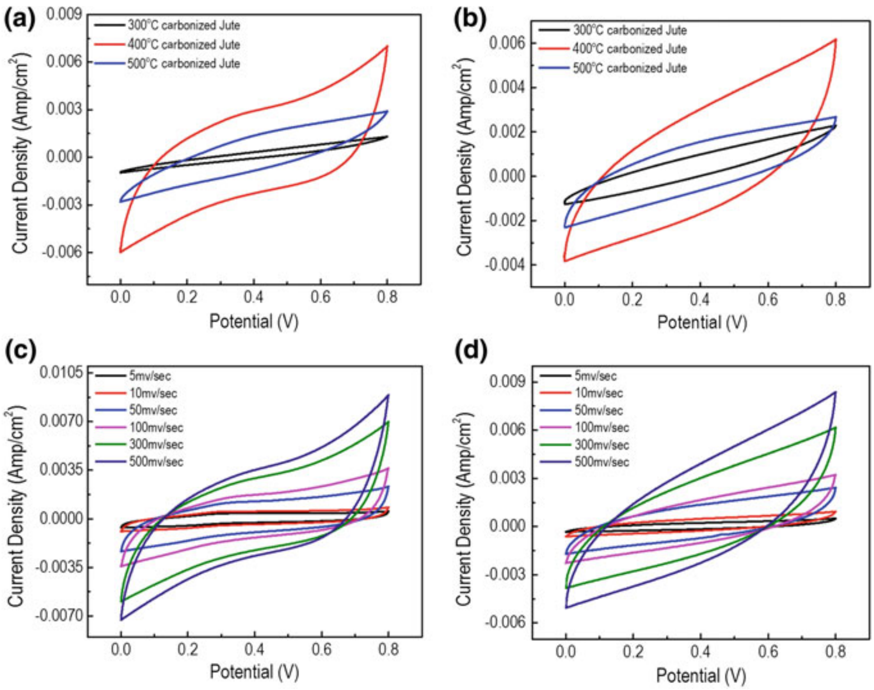

Fig. 4 Electrochemical characterization of bio-charred jute using cyclic voltametry (CV) of electrode and the device. **a** Comparing the CV of bio-charred jute electrode obtained at three different temperatures (300, 400 and 500 °C). **b** A comparison of the CV of the symmetrical or bi-functional device developed from the 3 different samples of bio-charred jute (300, 400 and 500 °C). **c** A CV for the 400 °C bio-charred jute electrode was performed at different scan rate from 5 to 500 mv/s, **d** Similarly a CV was performed for the device developed from 400 °C bio-charred jute device at different scan rate from 5 to 500 mv/s

stretching, deep peak at 1707 cm^{-1} for C=O showing vibration of ester groups (hemicelluloses), sharp trench at 1610 cm^{-1} for C=O stretching, 1247 cm^{-1} for –C–O–C– bond in chain of cellulose and 100–700 cm^{-1} for C-O stretching. These all peaks are matching with the published works of different researchers. [7, 8]

3 Search for a Bio-compatible Electrolyte

The next challenge was to screen a user-friendly, green, sustainable electrolyte material. The electrolytes which were screened are as follows: 1M H_3PO_4, 1M Na_2SO_4, 1M NaCl, 0.5M K_2SO_4, 1M NaCl + 1M Na_2SO_4. We made electrode and charge storage device using 400 °C carbonised jute, and performed CV analysis for these electrolytes. In Fig. 6 we have documented a comparative CV obtained using different electrolytes at 300 mv/s scan rate. Upon comparing the current density and

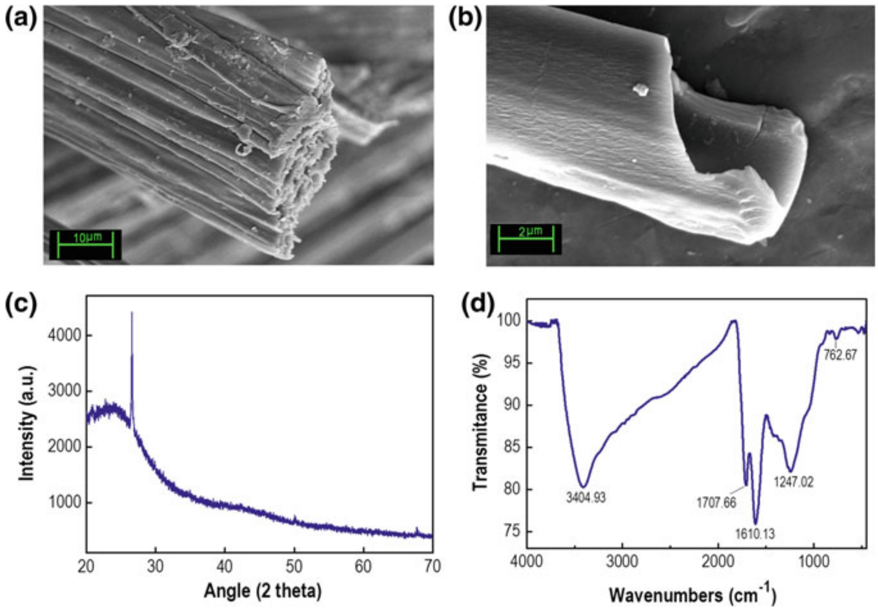

Fig. 5 Characterization of 400 °C bio-charred Jute, **a** Image of intake unburned Jute at 10 µm. **b** SEM image after bio-charred at 400 °C which shows proper hollow tube. **c** XRD pattern shows sharp peak which represent (002) plane. **d** FTIR pattern of carbonized jute

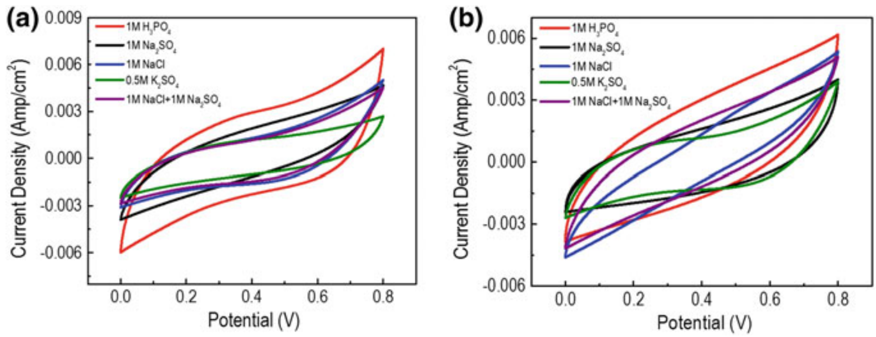

Fig. 6 Cyclic voltametry (CV) comparison of different electrolyte on electrodes and devices made from 400 °C bio-charred; **a** CV of 400 °C bio-charred jute electrode with different electrolytes: 1M H_3PO_4, 1M Na_2SO_4, 1M NaCl, 0.5M K_2SO_4, 1M Nacl + 1 MNa_2SO_4 at 300 mv/s scan rate and *red* trace of 1M H_3PO_4 showed significant results. **b** CV of 400°C bio-charred jute symmetrical device with the above mentioned five electrolytes at 300 mv/s scan rate. Best results were obtained from 1M H_3PO_4

specific capacitance for the electrode (Fig. 6a, **for electrode**) and (Fig. 6b, **for device**), the best results were obtained in 1M H_3PO_4 (Red trace). Phosphoric acid (1M H_3PO_4) is a bio-compatible, green electrolyte. The CV shapes is almost rectangular for 1M H_3PO_4 electrolyte as compared to other electrolytes which shows supercapacitive behaviour.

4 Stability of the Charge Storage Device

4.1 Stability Check by Electrochemical Characterisation

The next goal was to test the stability of the charge storage device developed from bio-charred jute (400 °C). We investigated its stability using two methods. In the first method, we investigated the specific capacitance retention property. To obtain it, we performed a charge-discharged cycle for 1000 times using the Basi cell stand C3 at a scan rate of 100 mv/s. After 1000 cyclic we observed that, the device retains 98.9% of the specific capacitance, as compared to the initial value. In the second method, we examined the current retention capability of the device. We performed a CV on Basi cell stand C3 at a scan rate of 300 mv/s scan rate for 1000 times and observed that it retains almost 100% peak current density value (Fig. 6b), even after 1000 cycle. Upon plotting the specific capacitance versus scan rate graph (Fig. 6a), we observed that as the scan rate increases, the specific capacitance decreases or in other words, at lowest scan rate, the device showed highest specific capacitance. We observe at 5 mv/s scan rate the specific capacitance was approximately 200 F/g and at 300 mv/s it was 40 F/g. We conclude from it that the device is showing very high stability and significant supercapacitor behavior (Fig. 7).

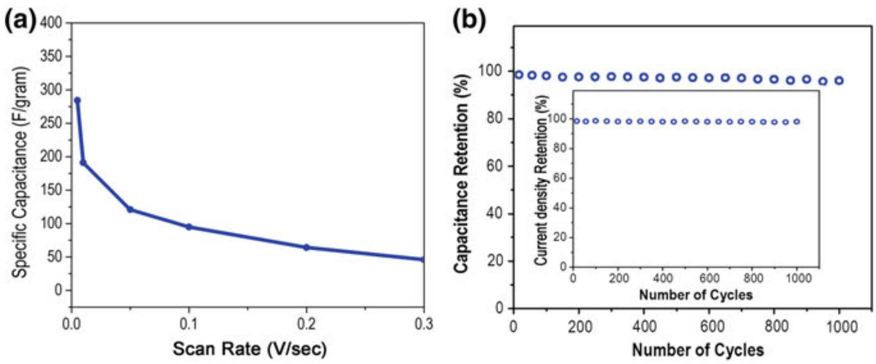

Fig. 7 Stability testing of the device. **a** A plot between specific capacitance versus scan rate of the device, **b** 1000 cycles of charge-discharge for investigation of specific capacitance retention and peak current density retention

4.2 Investigation Manually by Using Functional Charge Storage Device with Load

The Fig. 8, showed a functional charge storage device. In the supplementary video the charge storage device is being shown to power a 1.6 V LED and a 2.0 V DC motor (**Supplementary video S1** & **S2**). We observed that with just 1 min of charging of two devices (which are connected in series), the charge storage device can glow a 1.6 V LED for almost 20 min. Similarly it can run a 2.0 V DC motor for 10 min. We investigated it multiple times and the result were repeatable.

5 Proposed Model, Device Architecture and Discussion

The device CV shows the rectangular shape and charge discharge cyclic is almost symmetrical, which is suggesting that this device worked similar to a super-capacitor. Here, we are using bio-charred carbon tube as electrode material. The hollow nature of the tube resulted in significantly higher electrolyte holding capacity on the electrode surface, which further is added up with the electrode–electrolyte interface double layer capacitance and finally resulted in many-fold enhancement of charge storage capacity. When the symmetrical device was charged by connecting for the first time with power supply to charge the symmetrical

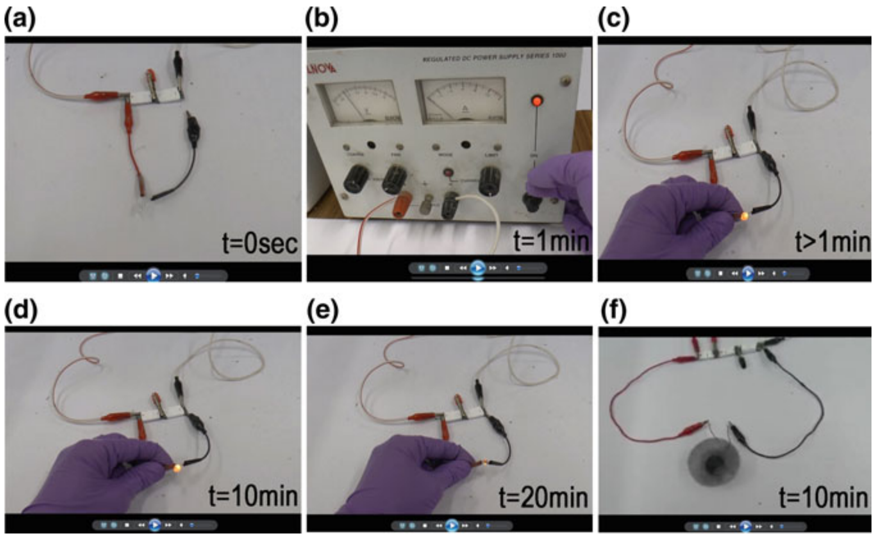

Fig. 8 Screen Shot of Video for manually testing the functionality of the devices. A functional charge storage device from bio-charred jute powering a light emitting diode (LED) and running a DC motor

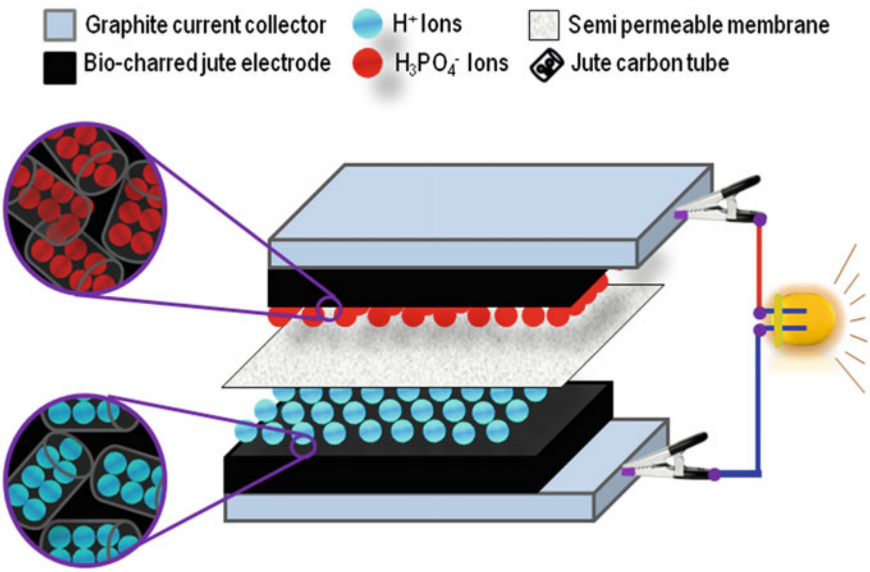

Fig. 9 Concept diagram demonstrating the storage aspect of the charge device. Here the ions of H_3PO_4 ($\mathbf{H^+}$ and $\mathbf{H_2PO_4^-}$)get stored in the hollow tubes of bio-charred jute

device, it creates a polarity on the individual electrodes and the electrolyte ions $\mathbf{H^+}$ and $\mathbf{H_2PO_4^-}$ migrate towards opposite electrodes, thus creating a polarity and creating the electrochemical double layer. [9] Apart from the double layer capacitance, some pseudo capacitance also generated due to some faradic reaction and a partly battery like behavior is also observed [9, 10]. Figure 9 diagrammatically showed the device architecture.

6 Conclusions

Here, a new innovative application of jute fibre is shown. The approach of transforming jute fibre to high quality carbon material through bio-charring for battery and supercapacitor devices could be a potential approach towards 'green electronics' and 'empowering the struggling jute industry of India'. This is an approach whose underlying principle is '*design approach for social innovation and sustainability*'. The key question what has been addressed here is '*how design approach could revive the struggling jute industry*?' The approach to transform utility of jute from 'gunny bags to electronics industry' is the 'critical, innovative design theme to bring a social change in the landscape of jute farming in India. This approach encompasses the basic theme to integrate jute farmers, basic chemistry, material science, device design and fabrication in one common string of Innovative design for sustainable growth.

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Connotations of Ecodesign: A Commentary on the State of Discourse

Ramani Krishnaswamy and Kumari Moothedath Chandran

Abstract Design, as a process of realizing a planned change, operates on specifications from the normative requirements and constraints emanating from the context of realizing the solution. The concept of ecodesign deals with principles that ensure a desirable state of the environment by appropriate design of products or solutions. There is a growing body of literature on ecodesign. However, perusal of the publications on the operational aspects of ecodesign points to a lack of rigour in qualifying ecodesign. This prompted the authors of this work to study the state of the discourse on ecodesign from the perspective of connotations of the term among engineering designers. The observations based on the scrutiny of the definitions of the term ecodesign from papers published in the years 2016 and 2015 in the Journal of Cleaner Production point to an undesirable situation of conveniently adapting interpretations of ecodesign to suit the design constraints sans justification and validation.

Keywords Ecodesign · Eco-design · Life cycle assessment

1 Background and Objective of the Study

Widespread reference to the term ecodesign (or eco-design) in the recent engineering publications conveys its popularity. Design for Environment (DfE) is another term that conveys the essence of including the specifications pertaining to the environmental impacts in engineering design. Multiple terms are used

The original version of the chapter was revised: Belated corrections in the Table 1 have been updated. The erratum to the chapter is available at 10.1007/978-981-10-3521-0_90

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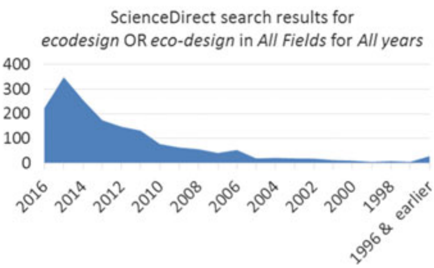
interchangeably to convey this concept of designing with environmental considerations. Brones et al. [1] highlights the varying vocabulary used to convey this concept by listing a set of keywords from prior publications, which are: *"eco-design", "ecodesign"; "design for environment"; "sustainable product development"; "sustainable product design"; "life-cycle design"; "life cycle design"; "green design"; "sustainable design"; "life cycle engineering"; "design for sustainability"; "environmentally conscious design".* The number of papers on ecodesign has been increasing of late (Fig. 1, left). Perusal of a selection of papers revealed that there are variations in the interpretation of the term ecodesign leading to multiple connotations. In this paper, the authors refer to the terms 'ecodesign' and 'eco-design' without distinction. This study aims to bring out the state of discourse in ecodesign by reviewing the definitions of this term from recent publications.

Several review papers are published in the literature on ecodesign methods and tools, the most recent papers being Brones et al. [1] and Pigosso et al. [2]. However, there has not been a review on the connotations of the term ecodesign itself. The aim of the review carried out by Pigosso et al. [2] was to classify the main trends in ecodesign tools and methods. Brones et al. [1] carried out a review on state of the art of ecodesign integration to management principles. In these two papers, it appears that the term is unambiguously defined, and the authors of the paper goes on to discuss about the methods and tools. The contribution of this work is a critical study on the term ecodesign in itself, focussing on the product engineering domain. This work takes a closer look at the connotations of the term 'ecodesign' to understand its usage after nearly 30 years of the UNEP publication by Brezet and van Hemel [3] and the paper on Design for Environment by Fiksel et al. [4]. The objective of this exercise is to bring out the convergence (or otherwise) of the operational definition of ecodesign for the benefit of engineering designers and its influence on communication. Other terms such as green design, design for environment etc., are not included in the scope of this work based on the premise that the findings may not be materially different from that of this study. To provide yet another proposal for ecodesign is not the intent of the work presented in this paper.



ScienceDirect search results for *ecodesign* OR *eco-design* in *All Fields* for *All years* by Publication title

Publication title	Count	Publication title	Count
J. Clean Prod.	527	Procedia Engg.	29
Procedia CIRP	121	Proc.- Soc. & Beh. Sc.	27
Res. Cons. & Recyc.	62	Sc. Tot. Env.	24
Energy Policy	48	Energy	23
Int. J. Prod. Econ.	45	Comp. Industry	21
Ren. & Sust. Energy Rev.	42	J. Env. Mgmt.	20
Waste Mgmt.	40	Design Studies	19
Energy Procedia	34	Ecol. Econ.	19
CIRP Ann.- Mfg. Tech.	32	Mat. & Des.	18
Energy & Bldgs.	29	Expert Sys. App.	15

Fig. 1 Search results from ScienceDirect using keywords "ecodesign" OR "eco-design" in ALL fields for all years, showing the number of papers published by year (*left*) and the number of papers published by publication title (*right*)

2 Approach of the Study

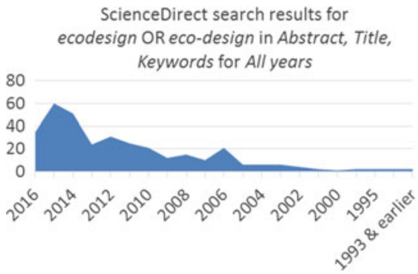
A search for the use of the term ecodesign in ScienceDirect resulted in a list of papers discussing the ways and means of designing and/or describing products meeting ecodesign requirements. The authors had access to ScienceDirect repository hence the search for papers is confined to this database. There are 1731 results for 'Article' or 'Review article' in ScienceDirect that has the term "ecodesign" or "eco-design" if a search is run in 'All Fields' for 'All years' under the 'Journals' tab. Thirty three percent of these articles were from the years 2016 and 2015 with the Journal of Cleaner Production (JClPro) having the highest number of papers (527 papers; 30.4% of the search results) among the publications titles (see Fig. 1, right).

Further to this, a detailed search with the criteria using the keywords "eco-design" OR "eco-design" in 'Abstract, Title, Keywords' to search among 'Article' or 'Review article', under 'Journals' tab for 'All years', resulted in 338 publications (Search date and time, 4 July 2016, 20:38 IST) (see Fig. 2). The variety seen in the descriptions and in the use of the term 'ecodesign', and the absence of a common operational connotation among these publications, prompted the authors to compile a select set of papers containing 'ecodesign' or 'eco-design' definitions or descriptions.

The criteria chosen to shortlist papers from the 338 publications are:

(a) **The number of publications by year**: The year wise distribution of the 338 papers showed that the number of publications with the term 'ecodesign' or 'eco-design' was increasing in the recent years (see Fig. 2, left). The list of publications from 2016 and 2015 alone has 95 (28.1%) papers.

(b) **Journals with higher number of papers with 'ecodesign' or 'eco-design' in 'Abstract, Title, Keywords'**: JClPro contains 163 papers, which is 48.2% of the 338 papers. Hence JClPro is the journal of choice for this study (see Fig. 2, right). An earlier review by Pigosso et al. [2] also highlighted this fact.



ScienceDirect search results for
ecodesign OR *eco-design* in *Abstract, Title, Keywords*
for *All years* by Publication title

Publication Title	Count	Publication title	Count
J. Clean Prod.	163	Energy	4
Procedia CIRP	20	Energy Procedia	4
Res. Cons. & Recyc.	18	Bldg. & Env.	3
Design Studies	11	Ecol. Econ.	3
CIRP Ann.- Mfg. Tech.	8	Env. Imp. Asses. Rev.	3
Mat. & Des.	8	IFAC Proc. Vols.	3
Sc. Tot. Env.	6	J. Env. Mgmt.	3
Expert Sys. App.	5	J. Haz. Materials	3
Procedia Engg.	5	Rob. & Comp. Int. Mfg.	3
Proc.- Soc. & Beh. Sc.	5	Surf. & Coat. Tech.	3

Fig. 2 Search results from ScienceDirect using keywords "ecodesign" OR "eco-design" in Abstract, Title, Keywords for all years, showing the number of papers published by year (*left*) and the number of papers published by publication title (*right*)

Applying the above filters to the search results with 338 publications (Years 2016 and 2015; JClPro) fetched 45 papers [5–48]. This work is based on the study of these 45 papers. To confirm the relevance of choice of time span and the journal, a similar search was run in Web of Science. In Web of Science, there are 575 records if a search is run for “eco-design” or “ecodesign” in ‘Topic’ and ‘Title’ under ‘Article’ or ‘Review Article’ for ‘All years’. Among these results, 127 (22.09%) papers are from the time span of 2016 and 2015, and 175 (30.44%) papers are from JClPro. For the years 2016 and 2015 in Web of Science, 51 (40.16%) papers are from JClPro. The percentages match with the ScienceDirect search output and this substantiates our choice of time span (2016 and 2015) and the journal (JClPro) for shortlisting the select papers for further review.

3 Observations from the Study: Variety in the Definition of *Ecodesign*

Perusal of these papers for the stated or referred definition of the term ecodesign resulted in the compilation shown in Table 1. Nineteen (42.2%) out of the 45 papers did not have any specific definition of the term ecodesign. This may imply an assumption of common understanding of the term among the readers. A citation check within the 45 papers revealed that, sixteen papers (36%) cited ISO 14040 [49], fifteen papers (31%) cited Brezet and van Hemel [3], and only five papers (11%) cited the ecodesign specific standard ISO 14006 [50]. Eighteen papers (40%) did not cite any of the three. This study anticipated more citations to the ISO standards 14040 [49] and 14006 [50], and the publication by Brezet and van Hemel [3], which is one of the early publications on ecodesign.

From Table 1, it could be seen that there are multiple interpretations of the term ecodesign. Going by this data, there is a potential hurdle to the evolution of a common understanding of the term ecodesign among the research community and designers. Several papers relate ecodesign to lifecycle thinking, limiting the scope of ecodesign to a selected subset of factors affecting the environment. However, there exists an inherent challenge in validating product Life Cycle Assessment (LCA), specifically in the ‘use’ and ‘end-of-life’ phases.

Interesting statements from a couple of papers from the reviewed papers, produced below, highlight the challenges in relating engineering design to ecodesign, where the additional eco-requirements of a generic nature add to the design specifications in an ad hoc manner. MacDonald et al. [31] propose, “Future eco-design studies must focus on achieving positive change in individuals’ behaviour using a combination of approaches.” Such a proposal augments the designer’s responsibility to non-engineering requirements like behaviour of individuals, validation of which is a matter of subjective evaluation and poses difficulty in establishing causality. The meeting of engineering specifications can be validated by technical performance

Table 1 Definition of ecodesign/eco-design from a selection of papers from JClPro published in 2016 and 2015

Author and Year	Definition (text quoted from the respective papers)	Ref.
Cascini et al. (2016)	This paper does not state or refer to the definition of the term ecodesign.	[5]
Bonou et al. (2016)	"The ecodesign framework presented in Fig. 2 was designed based on the international standards for ecodesign, specifically ISO/TR 14062:2002 and ISO 14006:2011."	[6]
Dalhammar et al. (2016)	"The Ecodesign Directive (Directive, 2008/98/EC) sets rules for energy efficiency,…"	[7]
Lee et al. (2016)	"Ecodesign is a systematic approach that gives consideration to the environmental aspects of a product, at the actual product design and development stages, with the goal of minimizing an adverse environmental impact (IEC 2009)."	[8]
Park et al. (2016)	The term eco-design appears only in the paper title. This paper does not state or refer to the definition of the term ecodesign.	[9]
Vieira et al. (2016)	This paper does not state or refer to the definition of the term ecodesign.	[10]
Annunziata et al. (2016)	"The concept of Ecodesign is defined as the integration of design aspects and environmental concerns in the development of product and services (Karlsson and Luttropp 2006) in order to decrease environmental impacts throughout different life cycle stages, without compromising other product and service criteria such as performance and cost (Johansson 2002)."	[11]
Dekoninck et al. (2016)	"'Ecodesign' is defined by ISO 14006:2011 as the integration of environmental aspects into product design and development with the aim of reducing adverse environmental impacts throughout a product's life cycle (ISO 2011)."	[12]
Cluzel et al. (2016)	"From this perspective, eco-design allows us to consider, manage and improve the environmental performance of products, processes and services (ISO 14006:2011)."	[13]
Moultrie et al. (2016)	This paper does not state or refer to the definition of the term ecodesign.	[14]
Richter et al. (2016)	This paper does not state or refer to the definition of the term ecodesign.	[15]
Rossi et al. (2016)	"In the industrial field, ecodesign represents an approach to consider and integrate environmental aspects in the product development process (ISO 2011) through the application of strategies aimed at reducing the negative environmental impact along the product life cycle phases."	[16]
Kulak et al. (2016)	The term eco-design appears only in the Keywords. This paper does not state or refer to the definition of the term ecodesign.	[17]

(continued)

Table 1 (continued)

Author and Year	Definition (text quoted from the respective papers)	Ref.
Sihvonen et al. (2016)	"Eco-design is understood in this paper as an environmental management approach which systematically embeds environmental considerations (EC) into an organization's generic product development (PD) practices (Lenox and Ehrenfeld 1997; Pigosso et al. 2013). While generic product development practices allow an idea to be transferred ready for markets in the form of a product (Ulrich and Eppinger 2012), eco-design seeks to ensure that a product's environmental impact throughout its lifecycle is addressed in these practices (International organization for Standardization 2011)."	[18]
Kuo et al. (2016)	"A typical eco-design process consists of twelve steps: (1) describe the reference product by environmental attributes, (2) conduct an environmental quality function deployment, (3) complete an environmental benchmark test, (4) perform life cycle assessment (LCA), (5) derive eco-design improvement strategies, (6) select redesign tasks, (7) make product improvements, (8) modify functions, (9) hold a creativity session, (10) evaluate solutions, (11) test the new product, (12) complete certification (Wimmer et al. 2004). Performing LCA is a key step in the ecodesign process (Vallet et al. 2013)."	[19]
de Souza et al. (2016)	"This concept, applied to Design, originated the Environmentally Conscious Design, also called Ecodesign or Design for Environment (DfE) (Dewulf 2013), defined by the Directive 2005/32/EG (2005) as the "integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle"."	[20]
Zeng et al. (2016)	This paper does not state or refer to the definition of the term ecodesign.	[21]
Cobut et al. (2015a)	"While the United Nation Environment Program (UNEP) report on ecodesign recommends the use of LCA for the entire system if the environmental impacts of the product system have not been yet investigated, others recommend a systematic use of LCA in the ecodesign process (Brezet and Van Hemel 1997)."	[22]
Cobut et al. (2015b)	"Ecodesign, also known as Design for Environment (DfE), can be defined as the integration of environmental concerns into product design."	[23]
Ahmadi et al. (2015)	"The LCA-based optimization is therefore a powerful tool for the eco-design of systems along their life cycle."	[24]
Salazar et al. (2015)	"Eco-design is encouraged through European regulations like EPR (Extended Producer Responsibility), REACh (Registration, Evaluation and Authorisation of Chemical substances), WEEE (Waste of Electrical and Electronic Equipment) and ErP (requirements for Energy-related Products). During the last decade, eco-design has been principally based on standards, mainly from the ISO14000 series, concerning environmental impact assessment and eco-design."	[25]

(continued)

Table 1 (continued)

Author and Year	Definition (text quoted from the respective papers)	Ref.
De Giorgi et al. (2015)	This paper refers to Brezet and van Hemel [3] for the term ecodesign.	[26]
Verhulst et al. (2015)	"Ecodesign is considered a sub-discipline within sustainable design that is defined as 'a design activity that aims at the integration of environmental aspects in product design and development, aiming to reduce adverse environmental impacts throughout the product's life cycle' (Brones and de Carvalho 2015)."	[27]
Küçüksayraç et al. (2015a)	"Based upon Crul and Diehl (2006), design for sustainability can be defined as product developing industries and their partners along the product chain considering the environmental and social aspects of their products and processes as key elements of long-term product innovation strategies and daily practices."	[28]
Küçüksayraç et al. (2015b)	"The main design for sustainability approaches are, (1) redesign, (2) benchmarking, (3) new product design and (4) product-service systems design (Crul and Diehl 2006)."	[29]
Benetto et al. (2015)	This paper does not state or refer to the definition of the term ecodesign.	[30]
MacDonald et al. (2015)	This paper does not state or refer to the definition of the term ecodesign. Paper emphasises Design for Sustainability.	[31]
Brones et al. (2015)	This paper does not state the definition of the term ecodesign, but points out the use of multiple terms in place of ecodesign—"In the sphere of environmental sustainability, though the term ecodesign is widespread and substantiated by ISO 14006-2011 (International Standard 2011), similar terms are still used."	[1]
Del Pero et al. (2015)	This paper does not state or refer to the definition of the term ecodesign.	[32]
Pacelli et al. (2015)	This paper does not state or refer to the definition of the term ecodesign. The emphasis is on recycling in this paper.	[33]
Theodosiou et al. (2015)	This paper does not state or refer to the definition of the term ecodesign. "LCA is a tool that plays a major role in the eco-design concept and enables the quantification of all environmental impacts… (Blengini and Di Carlo 2010; Luttropp and Lagerstedt 2006)."	[34]
Andriankaja et al. (2015)	"Considering environmental criteria in the same way as conventional design criteria is an objective the ecodesign approach."	[35]
Taghdisian et al. (2015)	"The general concept of eco-design is an essential way to reduce undesired environmental impacts of processes, systems and products."	[36]

(continued)

Table 1 (continued)

Author and Year	Definition (text quoted from the respective papers)	Ref.
Issa et al. (2015)	"Ecodesign is a proactive environmental management approach towards product design, which aims to improve the environmental performance of products without compromising the performance, functionality, aesthetics, quality and cost (Johansson 2002; Nielsen and Wenzel 2002)."	[37]
Moultrie et al. (2015)	"Medical devices are covered by The EU's 2009 Ecodesign Directive (EU Directive, 2009/125/EC) which outlines requirements for energy-related products and includes the explicit consideration during the design phase."	[38]
Daae et al. (2015)	The term 'eco-design' appears only in Keywords. This paper does not state or refer to the definition of the term ecodesign.	[39]
Moreira et al. (2015)	This paper does not state or refer to the definition of the term ecodesign. Four main 'eco' approaches and methods are listed in this paper (1) LCA, (2) Systemic Design, (3) DfX, (4) Product-Service system.	[40]
Ghazilla et al. (2015)	This paper does not state or refer to the definition of the term ecodesign.	[41]
Allais et al. (2015)	"Eco-design (ED) is defined as the integration of environmental constraints in the product development process (PDP) (ISO 14062, 2002). Its aim is to minimize the environmental impact of a product during its entire lifecycle."	[42]
Vidal et al. (2015)	This paper does not state or refer to the definition of the term ecodesign.	[43]
Ma et al. (2015)	This paper does not state or refer to the definition of the term ecodesign.	[44]
Yu et al. (2015)	This paper does not state or refer to the definition of the term ecodesign.	[45]
Go et al. (2015)	This paper does not state or refer to the definition of the term ecodesign.	[46]
Alaviitala et al. (2015)	This paper does not state or refer to the definition of the term ecodesign. "Life cycle assessment (LCA) has become a main tool of ecodesign (Finnveden et al. 2009)."	[47]
Kanda et al. (2015)	"Ecodesign mainly addresses material selection, packaging, part recyclability, modular structure, and functional optimisation within physical products."… "PSS design enhances ecodesign by incorporating service (repair, performance guarantee, take-back, etc.) into the design space."	[48]

metrics quantitatively, and by user testing for qualitative conformance. But, the requirements pertaining to the environment, which are the ‘ecodesign requirements’, the validation of which is a matter of the state of the environment, which is a dynamic entity. The meeting of ecodesign requirements are validated with comparative self referencing to the earlier design of the same product by engineering designers, say for e.g., reduced emissions. Ma et al. [44] affirm, “There are a number of tools currently in practice to achieve firm-level sustainable development.” This statement is intriguing because of the absence of any references and that Sustainable Development is still not a settled debate from the economic and social perspectives. Therefore, achieving firm-level sustainable development should have some caveats and a specific context of interpretation. Some economists, for example Beckerman [51], are also critical of the lack of additional insights Sustainable Development brings to the prevailing theories of economics in dealing with provisioning for the future needs.

Absence of an ‘agreed-upon’ definition of the term ecodesign is apparent from the variety of connotations seen in the reviewed papers. This pattern reaffirms the general observation that a definitive operational definition is elusive even as the principles of environmentally-responsible actions routinely figure in the discourses by the academia and the industry.

4 Summary and Points to Ponder

Knowledge of the engineering designer about the product’s estimated impact on its surroundings determines the scope of ecodesign. Hence, it is understandable that a generic definition of ecodesign remains at the level of principles. Even after 20 years of the UNEP publication on ecodesign by Brezet and van Hemel [3], convergence of operational definition of ecodesign is elusive. From the reading of 45 papers chosen in this study, it is apparent that a definitive list of operational aspects has not emerged so far. From the collated list of definitions it is evident that there is no binding definition of the term ecodesign even after a lot has been discussed and published on the ways and means of environmental protection and sustainable human actions.

Selective specification of reduction of Green House Gases (GHG) or improved energy efficiency or use of renewable materials, etc., considered in isolation from a larger set of indicators of environmental impacts, is implied as a sufficient qualifier of ecodesign in these papers. Seldom there is justification for excluding other aspects or indicators. Presumptive scenarios of the impacts in the use and end-of-life phases, from a life cycle perspective, render the ecodesign evaluations speculative.

Design is a complex and multifaceted phenomenon and in order to design, designers have to draw knowledge from diverse areas, methods and tools [52]. Blessing and Chakarabarti [52] describe, “If knowledge is not available, which is often the case, designers have to rely on assumptions while minimising the risks, or undertake research to generate this knowledge”. One may tend to justify that if designers can rely on assumptions while designing, ecodesign can also be based on assumptions when knowledge is not available. However, there is a difference between design and ecodesign in terms of the reference for validation. In design, in spite of the assumptions by the designers, the fundamental characteristics of the process do not change, i.e., from need identification to validation of designed solutions. Ecodesign is design with the explicit requirement of lowering environmental impacts of the designed solution. The crucial element of specification in ecodesign is the state of the environment(s) in which the solution will function. Ecodesign solutions will be realistic only if the environment is unambiguously characterised. If the 'eco' in ecodesign is a hypothetical entity then the concern about multiple interpretations arises. The difficulty in relating the claims by different authors about ecodesign is due to a lack of uniform basis for validation. With the increasing volume of literature in ecodesign and in the absence of a convergent operational interpretation, the engineering community is looking at varied interpretations of this term. Ambiguity of definitions in engineering design creates confusion in communication among engineering designers and stakeholders. Feasibility of a single definition is not what this work aims at and is not within the scope of this paper. Irrespective of whether a common operational definition is feasible or not, the quality of communication about ecodesign will improve, if there is acknowledgment about the risk of trivialising the scope of ecodesign to an arbitrary selection of specifications pertaining to environmental impacts with a conspicuous absence of validation. There is room for academic research to dwell on the prerequisites for the translation of ecodesign principles to a systematic practice.

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Part II
Design Creativity, Synthesis, Evaluation and Optimisation

A Tool for Generating New and Appropriate Methods for Supporting Various Design Processes

Bijendra Kumar and Prabir Sarkar

Abstract There exist various design methods for supporting a product design process, especially for creativity enhancement and problem solving such as, Brainstorming, Role Storming, Gallery Method, and TRIZ; however, most of these tools have certain strength and weaknesses. While many of these are popular in industries, it is often difficult to select the best tool for a particular design stage. In this work, we aim to develop a tool or platform which helps designers to generate methods appropriate to a set of design stages. We created a database of many available design methods and categorized them into the design stage for which it is meant to enhance the outcome. The designers can select from several best possible steps to generate a new method appropriate for a company and evaluate it. Further tweaking may be required to make this new method suitable for the company for long term usage.

Keywords Design research · Creative method · Design process · Product development

1 Introduction

Product design process is often complex. When working in an environment that requires lots of creative productions in a short duration and tight schedule, it is helpful to have a design method. A method is simply a set of steps, which we can refer to while recreating the path from start to a finished product [1]. Conceptual design generally have two kinds of steps: divergent to generate alternate concepts, and convergent to evaluate and select the concept [2]. Although, design methods generally focus on: Divergence, Transformation, Convergence and Articulation [3].

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One of the goals of design methods is to help designers understand the essential truths of making an object, resulting in more holistic solutions, providing insight, and enabling deep investigation of a situation, thereby grasping the inner nature of things intuitively [3, 4].

There exist various methods for supporting design process falling under the purview of creative methods. Many of these are being used in industries to support design process. As design process in industry becomes complex, often a design process may not contain all the stages of a standard design process viz., problem identification, solution generation, solution selection and solution implementation. Additionally, each of the stages of the design process could spread over time, that is, there may be a gap of many months between problems identification and solution generation. Some of the available methods are, Brainstorming, Role storming, Gallery methods and TRIZ; however, most of these tools have some strength as well as weaknesses. For example some tools are effective in problem understanding or requirement identification, some in idea generation, and some during idea selection and evaluation. Thus, it may be difficult to select which is the best tool for a particular need in a design process.

Moreover, design process may contain a new stage of design, for instance, we may need design for sustainability, design for manufacturability [5] within the initial or conceptual design process, for which the above design methods may not be suitable. Thus, designers may need to use a different method in each design phase and for each design method. Thus a designer is confronted with the problem of selecting the right method from among all available methods. There is no standard way to select a right method. Can we develop a method that is most appropriate for a set of particular design needs?

2 Literature Survey

Design researchers are always in search for new and effective design methods. Design research began as a recognizable field of study in the 1960s through a conference on design methods. Initially design research was defined as the research that is done into the process of design [6] however, the concept developed further later as, ‘Designerly ways of knowing’ was introduced in the late 1970s by Professor Nigel Cross, who first clearly expressed this concept [7]. Since then, this field of study has grown considerably, and both design education and design research have developed together into the new disciplines of design. Design research is a fast-growing field of inquiry with significant importance in terms of helping society to create products and processes of improved quality and for improving the environment in which we live [8].

Design methods for generating new solutions often contain steps to enhance creative outcomes. Creative techniques are methods that encourage creative actions, whether in the arts or sciences. These techniques focus on a various aspects of creativity, including techniques for idea generation and divergent thinking, methods of re-framing problems, changes in the affective environment and so on [9]. An appropriate combination of various creative and design problem solving theories were made to identify the influences of problem solving task on creativity in context to product design [10].

We studied large numbers of design methods and analyzed them. We found that design methods could be segregated into five categories: tools for defining the creative problem; tools for creating ideas; tools for evaluating and selecting ideas; tools for implementing ideas, and others (very few).

Defining the problem is the first step of solving a problem. This is a very important stage as changing the problem definition will change the solution [11]. We have studied many methods used in this stage such as ‘Value Analysis’ that identify and prioritized the function as well as analyze them in terms of cost and value to the costumer [12].

After the first steps of successfully defining a problem, next stage aims to create a lot of ideas for solving the problem, because it’s better to have lots of ideas to have a good idea [13]. Many methods used in this stage were studied, such as, ‘Brainstorming’ that requires a small group of people that are given with a defined problem to think upon, the group members suggest many ideas to solve the problem [12].

After a list of ideas is created during the idea creation process, we move onto idea selection methods for selecting the best idea among the list of generated ideas. This idea selection stage is important because our solution will change accordingly, in terms of effectiveness and cost depending on the ideas selected. Many suitable methods used in this stage were studied, like, ‘Concept Screening’ that generates evaluation criteria using baseline concept identification and then comparing and giving scores of options against baseline concept thus selecting the best idea among the list of ideas [12].

In the last stage of problem solving, we need to implement the idea that is the outcome of the preceding stages from problem definition to idea selection. Many idea implementation tools have been studied such as ‘Mind Mapping’ that defines the main subject first and then divides it into primary branch and sub branch to make a plan for execution of an idea [12]. We also noted that some techniques such as the ‘Mind Map’ is suitable for multiple stages of design.

3 Aim and Methodology

In this work, we aim to develop a tool or a platform which helps design researchers to generate methods appropriate for a set of design stages. For instance, a design company may need a design method that is appropriate for idea generation and design for sustainability, because they might be interested to generate only new sustainable solutions. While, another company might be interested to have a most appropriate and effective design method for solution evaluation against design for manufacturability criteria. To achieve the above aim we follow the following steps as methodology:

- First, we create a database of 24 design method available in literature that are often used during the design process. The design methods we consider are traditional design methods as well as the creative method of problem solving.
- Next, each steps of these design methods are further categorized into the design stage for which, it is meant to enhance the outcome. For instance, steps in Fishbone diagram are good for problem analysis, whereas, most of the steps of Brainstorming method are for idea generation, steps in Consensus Mapping are good for solution assessment and steps in Value Engineering method are suitable both for problem analysis as well as for idea generation. From an analysis of each step of the design methods considered, for each design stage we have several possible steps. We created a database of these steps (see Sect. 4).
- Next, we create a tool that uses this database, which designers can use to generate new methods. This tool has an interactive user interface that provides a platform for new method generation (see Sect. 5).

4 Database Development

As explained above, for each design method we have identified individual steps and also identified the application of these steps. Next we stored individual steps under five categories (i.e. different stage of design process): problem understanding, idea generation, idea evaluation, idea implementation, and others steps (rarely used). The steps which suit a particular stage is stored under that category, as well as the steps which suit multiple stages, are stored under multiple categories. For instance, 'Attribute Listing' method can be categorized into different steps as shown in Table 1. We know that this method is applicable for conceptual design phase, where we have several stages such as, problem understanding. While breaking the method into steps, we found five possible steps of this method (Table 1, Column 1), similarly we have identified the stage for which these steps are suitable (Table 1, Column 2).

Table 1 The process for breaking a method into steps 'Attribute Listing' [12]

Steps	Suitable category
1. Identify the product or process you are dissatisfied with or wish to improve	Problem understanding
2. List its attributes	
3. Choose, say, 7–8 of these attributes that seem particularly interesting or important	Problem understanding
4. Identify alternative ways to achieve each attribute via any idea-generating technique	Idea generation
5. Combine one or more of these alternative ways of achieving the required attributes, and see if you can come up with a new approach to the product or process you were working on	Idea evaluation

5 Tool Development

We developed a Graphical User Interface (GUI) to use this database with various available options to the users, such as, Create Method (using this one can create a new method for a design process). We further linked the categorized steps of database (Sect. 4) under four categories viz., method requirement, method preparation, method steps, and method conclusion, which user can skim through. Such a screen shot showing the GUI of tool is shown in Fig. 1, in which there are different options as discussed below:

- Method requirement: Contains various method steps that are suitable for method requirement. For instance, 4–6 participants are preferred for administrating Brainstorming method.
- Method preparation: Contains all the method steps that are suitable for method preparation. For example, participants may require some accessories for preparing the method such as, blank sheet, pen, pencil, working environment.
- Method steps: These that contain various steps categorized under five categories (problem understanding, idea generation, idea evaluation, idea implementation and others). When one selects a category such as 'Idea Generation' from the dropdown menu on the right, a new screen appears as shown in Fig. 2. This screen shows different options under 'idea generation', such as, what it use for, method name (original method), steps from the method, modification to suit

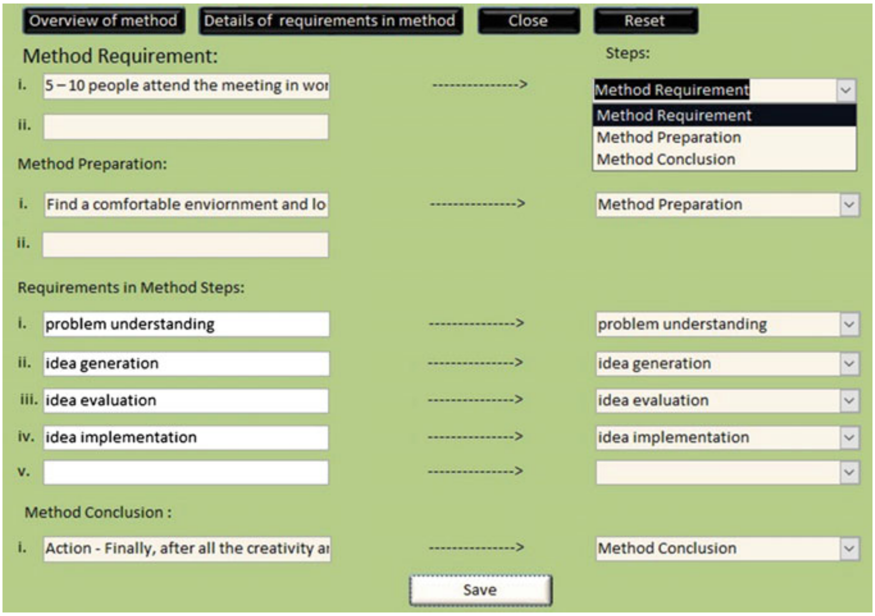

Fig. 1 Snapshot of GUI of tool

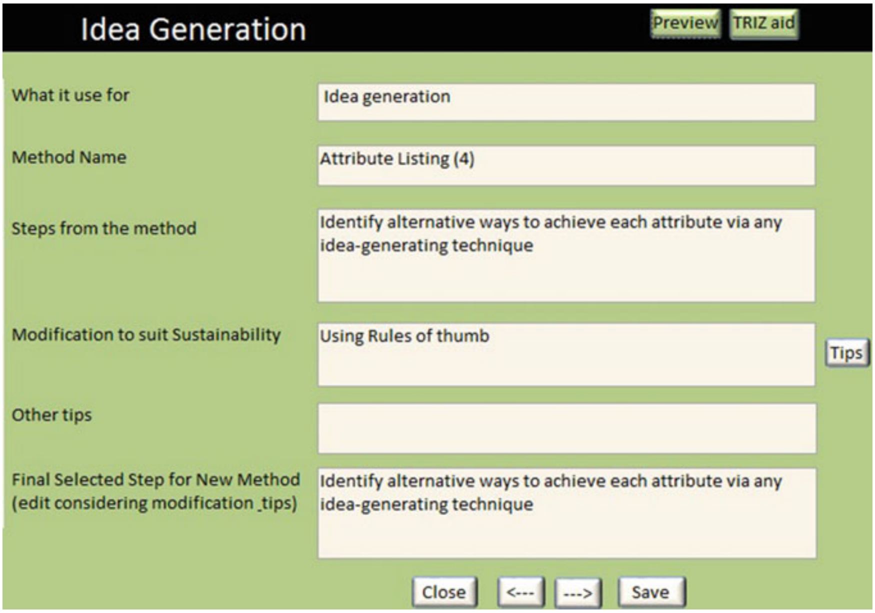

Fig. 2 A screen shot showing the requirement in method step of idea generation

sustainability (with Tips), and final selected steps for new method. A user can modify only the final selected steps if required and save the same.

- Method conclusion: Contains the steps which are identified suitable for concluding the method.
- The various steps are then saved together and can be viewed by the user using the "Method overview."

As discussed above different design firms follow different steps in designing. Also depending on the requirement a design firm may need to focus more on special requirements for the outcomes such as, design for sustainability and design for manufacturability. To use this tool, designers can follow the following steps:

- For generation of a new appropriate method, a designer first needs to note down the required stages of design process such as, problem identification, solution generation, solution evaluation and selection, including special requirements such as design for X, design for manufacturability, design for reliability, value analysis and recyclability.
- Next, the designers need to explore the steps available from the dropdown menu (as shown in Fig. 1 under method requirement) in the database and select the most appropriate steps for each of the stage as discussed above. The designer could also note the source method of each step provided by the tool. Further, the designer could also modify any step before adding it to the new method. For each stages of design, the designer can select one or more steps from the database.

- Since most methods have a background and closing section which contain information on how to administer this method, provision has been provided in the tool to add these steps into a new method. For instance, 4–6 participants are preferred for administrating Brainstorming method, is a background requirement for the Brainstorming method.

6 Evaluation of the Tool

First a new method is generated by a design researcher for helping the designer to generate ecofriendly solutions. This new generated method is evaluated with two experienced designer. Design experiments were conducted to assess the efficacy of a new design method developed using this tool. The steps followed for evaluation of the method are mentioned below.

Generation of a new method: The aim of the design method developed is to help designers to generate designs which are ecofriendly. The method is being generated by a design researcher who has some experience on ecofriendly design methods. This design researcher used the tool to select, or modify and save steps to develop a ‘new eco-friendly design’ method that is being explained below:

Method requirements:

- Form a group of 2–3 designers.

Method preparation:

- Assemble the designers in a quiet room
- Give access to sheets, pen, and pencils (for drawings)
- You are requested to discuss among yourselves audibly.

Method steps:

- Seat around in table and discuss the problem statement until understood and note all the required criteria that the solutions should satisfy. Add some criteria (may be 5–7) from the list of applicable sustainability criteria that are applicable for this problem (see attached list) (Source: Brain sketching, and Crawford slip writing).
- Generate lots of ideas individually. (Source: Brainstorming).
- Discuss each idea in group and see of these ideas are meeting all the criteria, if not, try to modify the idea to meet all the criteria. Cross out ideas that are not meeting the criteria or cannot be modified to meet these criteria (sustainability criteria) (Source: Brainstorming and Trigger session).
- Pool all the ideas, organize them according to sustainability criteria, classify them and select the best idea (source: gallery method).
- Make an action plan for the final idea and write, what, who, where, when, how, and why attributes of the idea of making it work in a sustainable way (source: simplex).

- Detail the final product and sketch it with approximate dimensions.

Method conclusion: None

Design Problems: The problems that were provided to the designers are as follows:

Problem 1. Design a table lamp in which intensity of the light can be altered depending on the requirement of the user, such as reading book (requires more light) or working in a computer (requires less light). You need to draw the solution on a paper or generate CAD drawing.

Problem 2. Design a windmill to harness energy from a flight while it is landing or taking off nearby. The design should not restrict the view of the pilot or pose any danger while flying. You need to draw the solution on a paper or generate CAD drawing.

Solving design problems without any method: We have evaluated the framework with two experienced designers, who were having more than three years of industry experience. The experiments were conducted in a closed room in a design lab at a premiere teaching and research institute. The designers are provided with blank sheets for drawing. These two designers are requested to solve two given problems, one after the other, while working together, without the use of any particular method.

Solving the problems with the method: Next, the designers are provided with the method as developed by the design researcher, stated above, in printed format, and are requested to continue solving the problems while using the new method provided to them. They are also requested not to reuse any previous solutions and to generate more new solutions. The entire design process was recorded, and the outcomes of the experiments were analyzed by the authors.

6.1 Results of Evaluation

The outcome of the design experiment was analyzed by expert using the 'environmentally responsible product rating' to assess the environmental friendliness of the outcomes. The seven criteria that is part of the environmental product ratings are: selection of low impact material, reduction of material use, optimization of production technique, optimization of distribution system, reduction of impact during use, optimization of initial lifetime and optimization of end of life. This framework provides an overall Environmentally Responsible Product Rating, which is based on Streamlined Life Cycle Assessment (SLCA) [14]. SLCA attempts to accept a degree of approximation while retaining enough precision to guide decision making. One of such approach is matrix type qualitative Life Cycle Assessment which is used in our analysis. The results of this assessment are shown in Table 2. We can see that even after getting exhausted of ideas when solving the problem without method, they will still be able to solve the problem while told to

Table 2 Environmentally responsible product rating of problem 1 and 2

Problem No.	Without method	With method	% improve
Problem 1	32	47	46
Problem 2	42	45	7
Average	37	46	24

use the method thus getting more ideas it shows that the new method has helped designers to improve eco-friendliness of the outcomes.

7 Conclusions

We understand that there is no one method fit all for all the design stages and even if there is such a method, it may not be the most effective one. Additionally, it may contain steps that are applicable for a particular design stage that the designers of a particular product or company is not interested in, or is not applicable.

In this paper, our aim was to develop a framework implemented in the form of a tool to help develop new design methods for different design firms. The methods can be generated for any stage of design process as per the requirements. We believe that this tool would be useful for design researchers in creating new methods for designers. It helps in channeling the thinking and focus of the designer systematically, as a result the output is more organized. Using this framework, one can select the most effective portions of different methods and create a new method based on the need of any design process. One can impart equal or different importance to the need for generating creative solutions and other requirements such as, eco-friendliness of solutions.

Additionally, applicability of the method that is, whether the designer needs a method that is more effective in problem analysis or solution generation can also be decided. For different requirements of a company, different methods would be created out of this framework. However, we considered 24 design method that are creative problem solving technique, and other methods can also be added to the database in the future work. The list is not extensive; however, addition of more methods should improve the efficacy of the developed method. Additionally, In the future work, we would attempt to provide a prioritized list of steps based on method efficacy studies of popular design methods from literature.

The framework or methodology is being implemented in the form of a tool. The tool also has additional features such as provision for searching different methods in database directly. Additionally we can upgrade this methodology by providing the rating to the methods based on effectiveness for the particular design stage so that we could get a perfect method out of it. Once a method is generated, the industry needs to evaluate the overall effectiveness of the new method with a set of sample design experiments. Further tweaking may be required or some steps may be need to be altered to make this new method suitable for the company for long term usage.

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Learning Aid in Braille and Typography

Siddhesh Sushil Shirsekar

Abstract This paper aims to study the existing braille script, highlight their inadequacies in teaching methods for small children and suggest probable solutions. The project focuses mainly on the use of braille and typography together using the existing braille script. In addition, this study is carrying its importance towards the beneficial development for visually impaired children in our society. Thus providing an educational aid. The main idea behind this project is to derive a piece of hardware to use to teach the visually challenged children for future.

Keywords Educational aid · Braille and typography · Base material · Readability · Book for learning basic alphabets · Research project

1 Introduction

Communication occurs when some environmental disturbance (the stimulus) impinges on an organism and the organism does something about it (making a discriminatory response) [1]. In the world of visuals, we have various typefaces for communication but in braille there is no such variety available in spite of new technical devices and special equipment for the blind are developing [2].

The following questions arise in one's mind:

1. Why relate braille and typography with learning?
2. Aren't the new innovative technologies supporting the braille methods of learning alphabets

Developing new way of learning braille with introduction of graphic symbols can fill this lacuna in the field of communication. Typography although not referred with technical aspects considering the visuals still has weight age with basic

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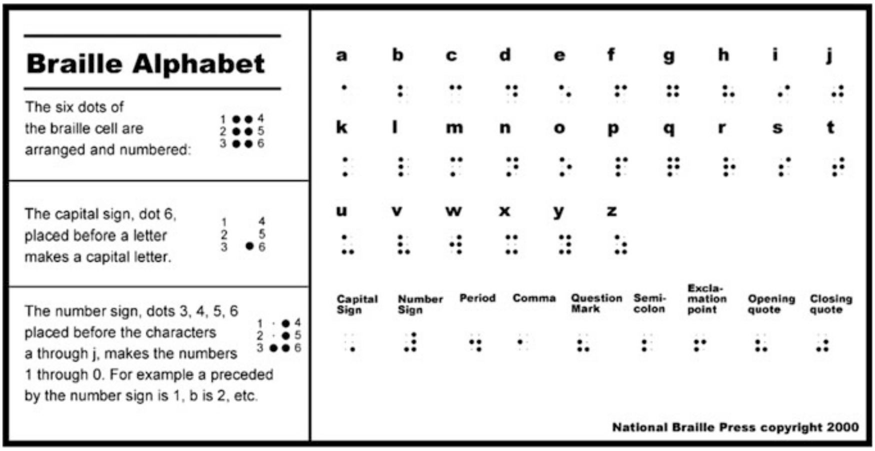


Fig. 1 Braille alphabet chart [6]

sansserif letterform learning for blinds. Sans serif letterforms are easy to read than serif letterforms [3].

Typography is the art and technique of arranging type to make written language legible, readable, and appealing when displayed. Various techniques were experimented before the invention of braille script but have unfortunately was not comfortable hence required the braille script [4].

Braille is a system of raised dots on paper that represent the letters of the alphabet that are felt by the fingertips of the blind in order to read printed language [5].

The study begins with placement of raised dots in a cell that was the germ for symbolizing the alphabets and the above braille alphabet chart as this research project is for the children from grade one to eight (Fig. 1).

2 Analysis

2.1 Learning Methods

The primitive methods of teaching braille are indifferent as the modern ways. Unfortunately, there is no such major change observed with respect to academics. Object identification is a difficult process to follow where discomfort observed for all objects. Both visuals and visually impaired children can grasp familiar objects easily [7].

Providing the path for the further access this current research created a study material a way to teach the blind children from kinder garden up to 8th grade.

Combination of braille and graphic symbols is important point.

2.2 Problems

1. It is difficult to understand the entire embossed picture.

The below is the use of tactile or tangible symbols no standard vocabulary of tactile symbols (Fig. 2).

There is development in the tactile symbol system using external objects along with the word introduction [8].

2. Change in the traditional braille slate pattern considering leading and tracking.

Any change in the traditional braille slate pattern can lead to misguide learning and make children difficult to fundamentals of learning the braille script. The following are the ideal universal measurements (Fig. 3).

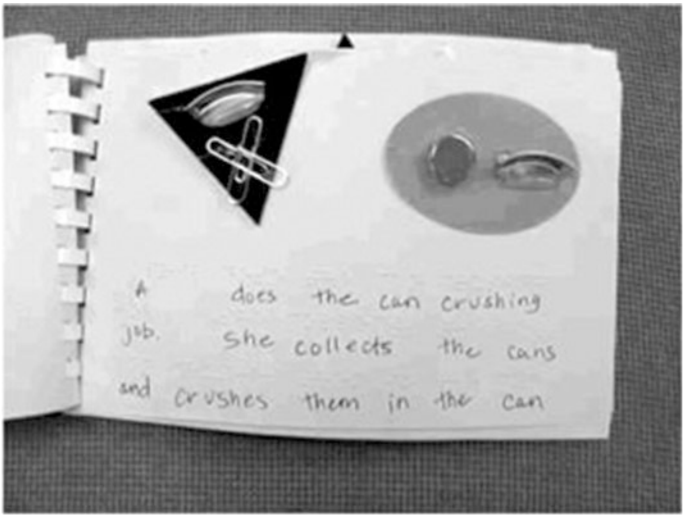


Fig. 2 A book that includes braille and tactile symbols

Fig. 3 Universal braille dimensions [9]

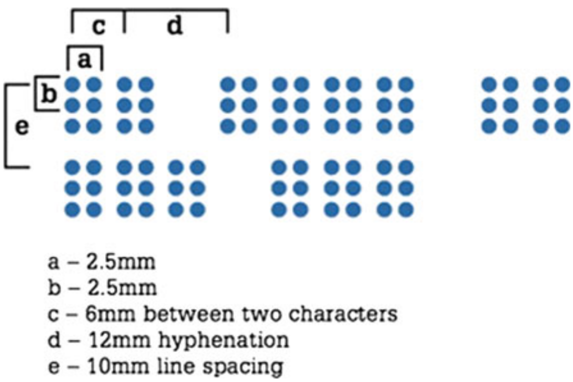


Fig. 4 Reading braille script [11]

3. The space distribution and surface.

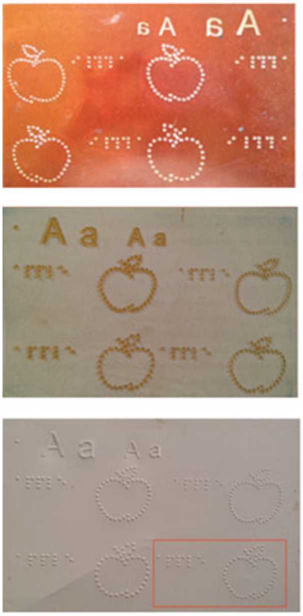
A minute change in the space distribution or size can make the child blank with reading and writing ability pace as the measurements are properly studied [10]. The paper used for the braille script is normal paper for academics purpose, becomes blunt over the period of usage (Fig. 4).

2.3 Statement

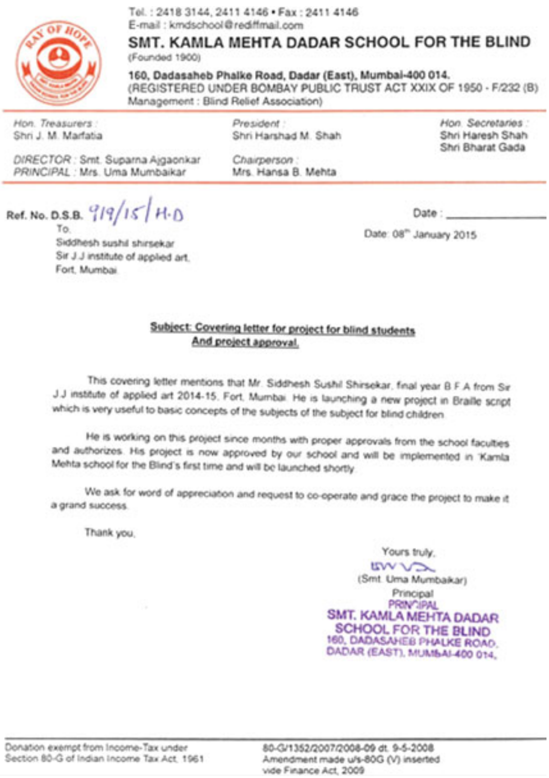
As stated above in the problem 2.2(3), The braille paper used during academic education with braille embossed on becomes blunt over the period of usage. Hence to overcome this issue an innovative technology is needed. Along with learning basic alphabets in braille the symbols needs to be taught in new ways in academics. Therefore, to provide easy and comfort for the blinds to identify new symbols and learn an experiment designed below using the existing braille and creating graphic symbols in braille itself.

2.4 Sampling Unit

Description from the Fig. 5, the ideal universal measurements for word are intact and only symbols spacing are changed.



1. 2. 3.



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SMT. KAMLA MEHTA DADAR SCHOOL FOR THE BLIND
(Founded 1900)
160, Dadasaheb Phalke Road, Dadar (East), Mumbai-400 014.
(REGISTERED UNDER BOMBAY PUBLIC TRUST ACT XXIX OF 1950 - F/232 (B)
Management : Blind Relief Association)

Hon. Treasurers : Shri J. M. Marfatia
President : Shri Harshad M. Shah
Hon. Secretaries : Shri Haresh Shah, Shri Bharat Gada
DIRECTOR : Smt. Suparna Ajgaonkar
PRINCIPAL : Mrs. Uma Mumbaikar
Chairperson : Mrs. Hansa B. Mehta

Ref. No. D.S.B. 919/15/H.D
Date : ______
To,
Siddhesh sushil shirsekar
Sir J.J institute of applied art,
Fort, Mumbai

Date: 08th January 2015

Subject: Covering letter for project for blind students And project approval.

This covering letter mentions that Mr. Siddhesh Sushil Shirsekar, final year B.F.A from Sir J.J institute of applied art 2014-15, Fort, Mumbai. He is launching a new project in Braille script which is very useful to basic concepts of the subjects of the subject for blind children.

He is working on this project since months with proper approvals from the school faculties and authorizes. His project is now approved by our school and will be implemented in 'Kamla Mehta school for the Blind's first time and will be launched shortly.

We ask for word of appreciation and request to co-operate and grace the project to make it a grand success.

Thank you,

Yours truly,
(Smt. Uma Mumbaikar)
Principal

PRINCIPAL
SMT. KAMLA MEHTA DADAR
SCHOOL FOR THE BLIND
160, DADASAHEB PHALKE ROAD,
DADAR (EAST), MUMBAI-400 014.

Donation exempt from Income-Tax under Section 80-G of Indian Income Tax Act, 1961
80-G/1352/2007/2008-09 dt. 9-5-2008
Amendment made u/s-80G (V) inserted vide Finance Act, 2009

Fig. 5 Sampling units to finalize braille symbol proportion along with project approval from the Smt. Kamla Mehta Dadar school for the Blind, India

1. Reverse Metal block with sample sizes of braille dots in symbol.
2. Inverse Nylo sheet with sample sizes of braille dots in symbol.
3. Final output selected sample in red box with readable proportionate dots with proper inters spacing in symbol.

The above experiment conducted with blind children with their mentors.

2.5 Base Material with Data Analysis

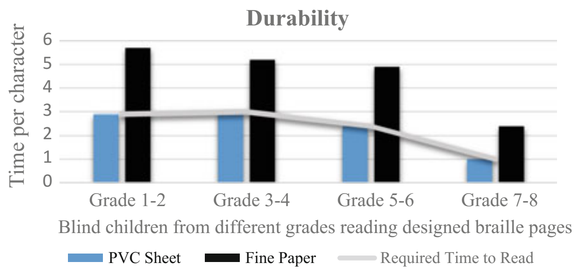
Aim: To experiment with the reading speed and durability of the designed braille pages.

Subject: Random blind children (boys and girls) from grade one to grade eight.

Study material: Fine paper (120 gsm) used by majority blind schools, laminated PVC sheet.

Content: Both the pages (fine paper) and laminated with designed page from current research project.

Fig. 6 Experiment on durability of papers



Experiment:

The experiment conducted with children from different grades by giving them same and different designed braille pages. To minimize the error, individual child was not given same page twice, so that he can read the content freshly rather than recollecting it from the prior exercise.

To group of children initially told to read different designed pages of fine paper (120 gsm) and laminated PVC sheet.

Experiment conducted for a week with equal time span to minimize the level of interest of individual child considering age difference and grasping power according to their learning grades.

Observations:

1. The fine paper was easy to read during first exposure.
2. Using the fine paper page repeatedly deteriorated the surface quality.
3. There was uniformity in laminated PVC sheet throughout the experiment.
4. Speed for laminated sheet was constant but not the case in fine paper.
5. As the grades increased the speed of reading increased.

Result:

From the below chart (Fig. 6) it can be studied that as we go towards the higher grades the readability speed increases with uniform results between PVC sheet and fine paper. The children also found PVC sheet easier to understand, as the dots were sharper than fine paper making it more durable.

The experiment conducted under the guidance of the faculty from Smt. Kamla Mehta School for the Blind, India.

Conclusion:

The laminated PVC sheet is more durable and easily readable with speed as compared to fine paper.

3 Aims and Objectives

As mentioned earlier the main aim of this project is to provide educational study material for the children from kinder garden up to 8th grade.

Perception towards this project motivates to derive simple graphic icons that are traditionally drawn. For visuals, we have plenty of study material but there is lack of basic study elements for blinds.

3.1 Problem Definition

The visual charts are easy to deliver as they are in two-dimensional form but for blinds, they need to be in embossed three-dimensional patterns. The current syllabus teaches the object with sensory learning methodology were the children are made to touch the objects. e.g. A for Apple (realistic apple given to touch).

However, it is not possible in all cases for words such as knife, lion, volcano, etc. Here the key idea is to approach the problem and to find a way out of this by providing a handy and comfortable book with embossed structures.

In this, project an attempt done to develop a structural educational medium to aware the child about the alphabets, words and outer form not proportions.

3.2 Approach

For smaller objects like apple, flower it was easy to give him for sensory learning but it was difficult for larger objects like airplane, elephant, etc. However, this is a fundamental book to introduce alphabets and words irrespective of the proportions, which we also not see in books for normal child. Therefore, to get a braille symbol each objects vectored in simplest form (Fig. 7).

Following the above process all the alphabets were design with four symbols each.

Another important way of introducing the visual letterforms was a challenge in this project. However, after experimenting with the blind and partial blind it was confirmed that it was providing an ease for the child to understand and differentiate the Roman alphabet with uppercase and lowercase (Fig. 5).

Below are the contents of a single braille book page from the research project along with actual designed page to the clear concepts.

1. The braille script alphabet A (braille point positioning 1)
2. Roman letter (uppercase and lowercase) for future communication purposes like signature, writing, etc.
3. Word APPLE embossed in braille script followed by healthy spacing to avoid confusion.
4. Symbol of graphic apple with same braille space and measurements testified from sampling unit (Sect. 2.4).
5. Followed by the next alphabet with proper spacing each page consists of two alphabets (Fig. 8). (Two-line space for new beginning followed in academic education).

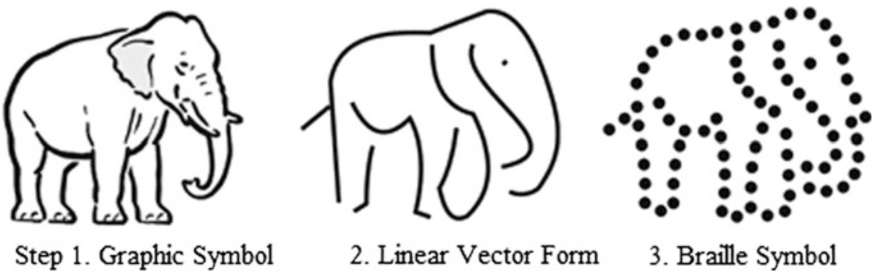


Fig. 7 Process of realistic elephant converted into simplest graphic with essential characteristics and then into braille symbol

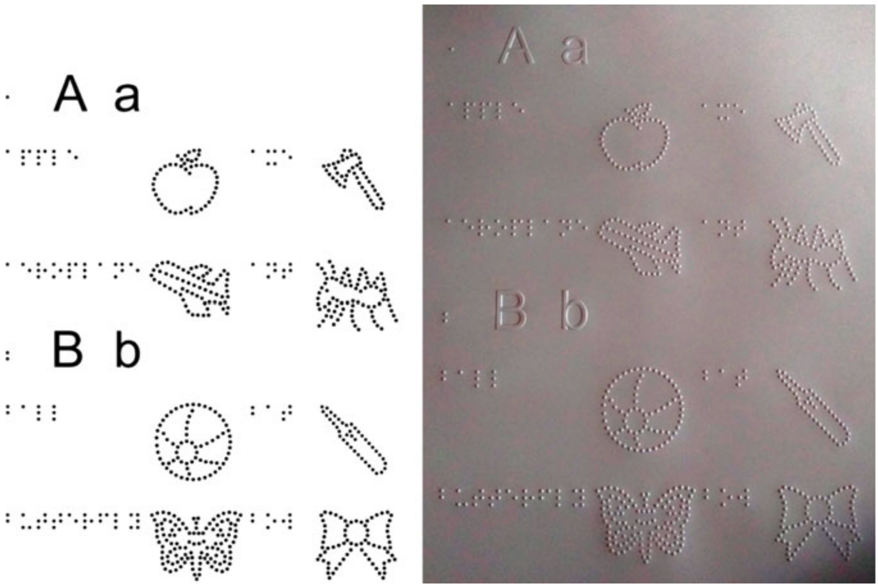


Fig. 8 Final output of designed page in graphic (LHS) and implemented (RHS)

4 Conclusion

1. This basic book from research provides ease for children to learn the alphabets with symbols.
2. Compilation of visual alphabets, provide an introduction and letter identification for future use.

3. It also guides to identify objects and shapes through graphic forms.
4. Sufficient space in the book helps to learn and enhance their sensitivity skills and grasping power.
5. Ideal universal measurements kept intact for writing words, giving same reading pace and convenience for the child.

Braille and Typography together can provide an educational aid, which is testified research for visually impaired children in our society using existing braille script. Therefore, to teach blinds this book is useful which is certified by Smt. Kamla Mehta School for the Blind, India and is currently being used for academic purposes. Thereby making blinds individual learners and can aid them to identify objects on easy platform.

5 Future Plans

Book versions can be further developed with word expressions, various strategies can be implementing with respect to tools, mediums, and surfaces.

Acknowledgements I would like to express my sincere gratitude to Prof. Santosh Kshirsagar from Sir J.J Institute of Applied Art, India, Prof. Samip Sawant, Dr. Sushil V Shirsekar,

Faculties from Smt Kamla Mehta School for the Blind, India- Mrs. Uma Mumbaikar, Mrs. Kunda Ajgaonkar and Mrs. MadhaviGawde.

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Designing Learning Experiences for Problem-Solving. About Mindblower

Karla Paniagua

Abstract The work describes the process of researching, designing and prototyping a national standard to certificate competencies for inventive problem-solving, according to the formal framework for competency-based certification of skills, current in Mexico.

Keywords Creativity · Creative economy · Competency-based learning · Prototyping · Learning models · Certification

CENTRO Advanced Design Institute (CADI) is a private higher education institution founded in 2003 in Mexico City. Its area of specialty is Creative Economy [1], an i.e. productive environment that makes inventiveness its primary raw material. This area includes design, publishing, film, television, art production, crafts, and games industry [2], among other scopes that this institution considers to create undergraduate, postgraduate and continuing education programs.

Creative Economy contributes to local and regional development through the so-called creative class [3], which generates jobs, promotes the connection between cultures, social mobility and through all this, development. Designing training models are a crucial part of this segment, so CADI contributes to the Creative Economy by forming professionals and delivering learning models.

In 2013, CADI opened the Center for Research in Creative Economy, dedicated to generating and disseminating knowledge in the area of specialty of the institution. This coordination currently has four research lines running: Creative Economy (policy analysis); creative processes (analysis and evaluation of techniques and methods); prospective design and social design. These findings are related to the work on the field of the line of creative processes.

The line of creative processes focuses on the synthesis and evaluation of techniques for lateral thinking [4]; divergent thinking [5]; and systematic inventive thinking [6]; among other ways to develop creativity. For the purpose of this

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presentation creativity is “the tendency to generate or recognize ideas, alternatives or possibilities that could be helpful to solve problems, communicate with others, or entertain oneself or others”, according to Franken [7].

The result of these explorations has become in recommendations to improve the institution’s study plans, as well as designing experiences not associated with undergraduate or graduate programs, but rather with continuing education programs for general public.

These learning experiences turned into courses tailor-made for organizations, such as the National Evaluation Center for Higher Education, the National Council of Science and Technology, the Global Wellness Institute, and the world Presidents Organization (WPO), among other national and international institutions.

This sustained work with organizations allowed us to realize the opportunity to train stakeholders in problem-solving. That is to say, training key employees so they can ideate, design, test and implement solutions related to the working environment, productivity, organizational structure, development of new products and services, among other common challenges. We have also verified different ways to transfer problem-solving know-how so that it can be learned and practiced more smoothly and successfully.

The formative experience which we will refer to is a method for problem-solving that integrates into a fluent and logic sequence the most useful and illuminating techniques, identified by the research team during the last two years. It is also an instrument for national certification of skills in problem-solving with the endorsement of the National Council for Standardization and Certification of Labor Skills; that means that is a reference harmonized with other international standards.

Mindblower is a learning experience consistent with Paul Guilford’s findings [8] about competency-based training programs. In that vein, we must say that the model distances itself IQ and memory assessments, being closer to more complex levels of cognition in accordance to Bloom’s taxonomy [9], i.e. creating, prototyping and evaluating.

1 The Research

From 2014 to 2015, the Research Center team compiled, categorized and evaluated hundreds of techniques that encourage creative thinking, from the classics to the very latest. This exploration resulted in a database that describes 197 procedures that were classified based on the type of product that it generates (Table 1) and the kind of cognitive process that it involves, according to Bloom’s taxonomy (Table 2).

The search universe to compile the corpus was very broad: books, articles, blogs, vlogs, informal interviews with teachers and trainers, etc. All the information was systematized, allowing us to identify trends [10]. We observed that most of the techniques generate visually represented or written ideas, while a small number of methods lead to prototyping. We also realized that brainstorming is suggested

Table 1 Types of deliverables

Deliverable	Number of techniques
Idea	123
Visual representation	48
Statement	18
Multimedia representation	19
Prototype	9
Other	9

Table 2 Cognitive process involved according to Bloom taxonomy

Process involved	Number of techniques
Knowing	58
Understanding	64
Applying	32
Analyzing	92
Synthetizing	80
Evaluating	43
Other	

consistently in literature, even though it produces inefficient results in practice. Finally, we distinguished techniques different from brainstorming that allow inspiration and systematization thinking, generating better results.

Another insight was that most of the techniques are conducive to the generation and analysis of ideas, but very few involve the application of the designed solutions. This result is directly related to the infrequency of techniques that lead to prototyping (Table 1), crucial to achieving implementation.

The research team selected the methods that were more successful, over 23 test sessions with students, teachers, and participants from those companies that we regularly provide. We noted that the participants reached better and more inspired results when:

1. Enough time to identify and analyze the problem or set of problems to be solved is dedicated.
2. Enough time to investigate the problem, its causes, effects, participants and surrounding elements is dedicated.
3. Less brainstorming and more systematic thinking is employed.
4. Certain key moments for unprejudiced reflection are induced.
5. Enough time is dedicated to prototyping the possible solutions.
6. Enough time is dedicated to pitching the solution and receiving feedback from observers outside the creative process before implementation.
7. The participants understand that making mistakes is a common and expected part of the all creative process.

While the investigation unfolded, the team extensively discussed the results of the 2014 survey of professional skills by the Research Center for Development (Mexico), a think-tank whose work revealed that university training programs have failed to meet the primary professional market requirements [11]. The ability to solve problems is part of the list of skills required by the professional field that curricula are failing to encourage in students. This finding coincided with our insights during testing sessions and show us the way forward.

We noticed that many programs to certify creativity have proliferated in Mexico. There are currently at least ten specific initiatives for certification of creativity, considering only the ones in the central region of the country, all of them are experiences between 50 and 160 h. None of these have the support of an official certifying institution that guarantees the endorsement through a harmonized instrument with other international standards, so from this perspective, many of this programs are not real certifications, rather training programs called in that way to appear more trustworthy.

The team collected and reviewed 182 instruments issued by 38 international organizations for the certification of creativity and innovation and skills. This state of the art showed that only 1.8% of these standards (Table 3) or units of larger instruments, identified mainly in Europe and Oceania, focus on creativity, considering that we understand creativity as problem-solving. Although still very marginal, the outcome was favorable: other countries have embraced the adventure of designing instruments to certify creative skills with the support of internationally harmonized agencies.

The selected standards (Table 3) have and endorsement from public or private institutions and are explicit about performative, conceptual and attitudinal criteria. We considered both complete standards and units are corresponding to higher learning instruments to certify management processes innovation creativity,

Table 3 Standards focused on creativity

Instrument	Year	Country
1. BSBCRT601A—Research and apply concepts and theories of creativity	2008	Australia
2. CCSDES32—Apply concepts and principles of creativity and innovation to your own design work	2009	United Kingdom
3. CCSFL10—Plan innovation for your freelance work in creative and cultural	2009	United Kingdom
4. SKSJ6 Contribute to creativity and innovation in journalism	2010	United Kingdom
5. 15627.2—Demonstrate creativity in meal preparation and presentation	2010	New Zealand
6. SCDCCLD0410—Lead the support for children's creativity	2012	United Kingdom
7. L/506/7509—Innovation and Creativity	2014	United Kingdom
8. CHCECE018—Nurture creativity in children	2014	Australia
9. BSBCRT403—Explore the history and social impact of creativity	2014	Australia
10. S.R. CEN/TS 16555-6:2014—Innovation management —Part 6: Creativity management	2015	European Union

productivity, etc. The team went deeper analyzing this tools, the creativity concept described on each one and the different skills associated with creativity. This task originated a framework for the new standard.

The review of these materials allowed us to conclude that it is possible to certify creativity as an approach to problem-solving (organizational, professional, industrial, etc.). Also, we noted that international standards do not focus on a restrictive notion of creativity or an only technique to facilitate it, but they are broad on their scopes.

With these outcomes in mind, the team identified an opportunity to bring together the most powerful techniques tried and improved across the years in a single learning experience for general public (not only our customary students), validated by the Council as mentioned above, the first of its kind in the country: this model was call Mindblower.

Minblower's structure is inspired by a typical design process [12], but goes further including systematic inventive thinking, storytelling, foresight and risk control phases, among others resources. The techniques pretend to push the participant outside the comfort zone and guide him through an intensive and creative journey. The primary goal is that at the end of the experience, the participant will be able to identify and reflecting on a problem, analyzing it in depth, prototyping viable and enlightening solutions and designing a follow-up plan.

Mindblower components are not new, but the combination does involve improvements about known models. In this sense, the model consolidates institutional experience and research insights in an effort of incremental innovation.

2 Mindblower©

2.1 The Learning Experience

Mindblower is a 101 h experience divided into eight blocks inspired by the different stages: Introduction to the method, visualizing, diverging, converging, prototyping, optimizing, improving the storytelling, foresight, and risk control. The program includes alternates several deploying sessions (pitching) to receive feedback and refine the solution.

In the opening stage, participants become familiar with design thinking, its scope, and benefits. Also, they complete Torrance [13] (Fig. 1) and Basadur [14] tests for the purpose of identifying their creative potential. Through this state, they learn fieldwork principles and practice with tools and techniques as fieldwork diary, participant observation, and in-depth interviews [15], to be able to understand the user point of view.

Through the following stage (visualizing), the participants will learn visual thinking's nomenclature, this will be the primary language that will help to

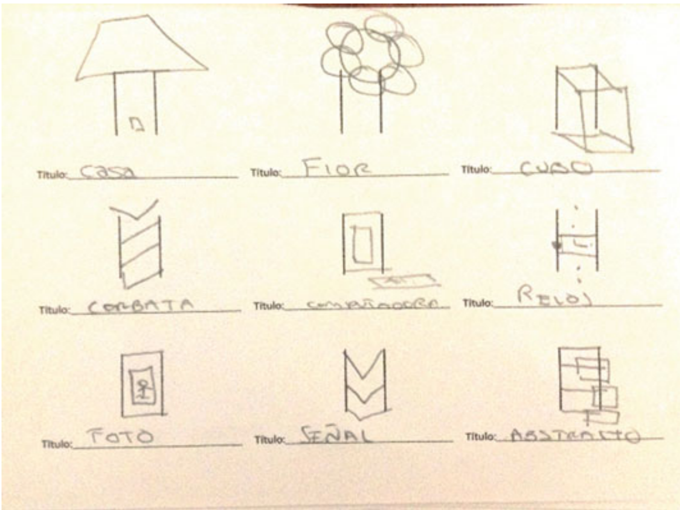

Fig. 1 Torrance test

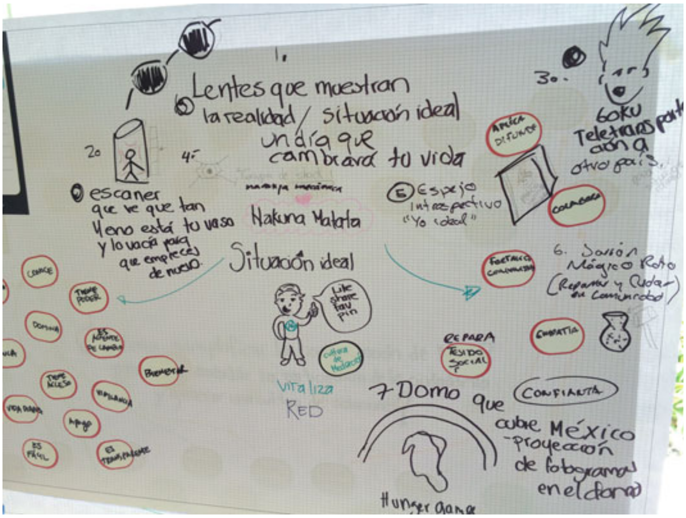

Fig. 2 Visual thinking

organize, analyze and communicate the ideas no matter what professions the participants may have [16] (Fig. 2).

In the divergence phase, the participants will learn and practice different ways to get inspired, like coolhunting, brainwriting, lotus flower, among others [17]. In the convergence stage, they will learn and apply the principles and techniques of Systematic Inventive Thinking (SIT©), so they can observe the problem and the possible solutions through this powerful analyzing looking glasses.

Fig. 3 Prototyping with LEGO

During the pitching sessions, the participants will present the ideas and receive feedback from guest judges and their partners, to improve the solution sketches, the visual thinking strategies, the storytelling and the critique skills.

During the prototyping stage, participants will use the LEGO© Serious Play© (Fig. 3) [18] technique to materialize the proposal and assess its scope. The result of this step is presented again on a pitching to receive feedback from experts.

In the storytelling phase, participants learn and apply the principles the narrative and the design of every proposal, training their body language and staging skills at the same time, so they can go as far as they can to achieve a significant project and performance [19].

Through the foresight module, the participants will use futures archeology, trend scanning, design fiction and speculative design to take the solution to a new level. What would happen if this problem occurs in 30 years in a utopic or dystopic scenario? In which way, this context should affect the solution? These are some of the questions that they must face to outline a sharper, deeper and lasting solution [20].

Finally, the participants will evaluate the risks, design specific goals, tasks monitoring criteria and success indicators to follow up the implementation [21].

2.2 *The Standard*

The standard that endorses the certification program in its current version includes six elements to be considered for assessing applicants: problem identification, solution design, solution prototyping, implementation plan, monitoring and case analysis.

The structure of the standard is much less complex than the course. The instrument must satisfy the guidelines of the National Council for Standardization and Certification of Labor Competencies and hopes to be more open, less restrictive, and consistent with the results of the state of the art.

2.3 The Products

Mindblower is above all, the guideline for a designing experience. Its products are diverse: canvasses with ideas, sketches, drawings, diagrams, prototypes, matrix, scenarios, and plans. In sum, all these elements aspire to be anchors and scaffolds [22] of a solution. What kind of solutions will produce? The range of possibilities is wide, as the range of organizational problems that we will face.

During the pilot sessions, we observed that participants who do not come from the field of design and art, are reluctant to sketch and prototype initially, arguing weak fine motor skills or little talent to draw. As well, designers and artists are unwilling to research or think systematically, arguing that this kind of activities will inhibit their creativity.

It seems the initial stages take out participants from their comfort zone, which is some of the effects we are looking for, at least at first. After this uncomfortable glance, the process will induce inspiration, encourage them to face risks and to experiment error as a normal part of the process, to ideate and synthesize different solutions than those which would come to their minds during a simple brainstorming session.

The coaches work hard to break the culturally learned pairing of creativity as an expression exclusive of the artists. They reinforce the confidence of participants, emphasizing on that creativity is a muscle that we must train, a skill that can be learned and practiced formally in inspiring environments that encourage free thinking, but also systematic, conscious of the resources that we have in the universe around the problem.

3 Discussion and Conclusion

In the recent days, we have achieved the following advances:

1. Founding a committee recognized by the Council to develop the standard that will endorse the certification program
2. Designing, evaluating and improving the proposed standard with control groups
3. Assessing and enhance both the certification and the standard models

4. Learning how to deal with our prejudices about making mistakes, and with those who claims that creativity cannot be evaluated or certified because it is the result of pure inspiration.

The most important pending issue is the conclusion of the standard and its publication in the Official Journal of Mexico, planned for October 2016. To achieve this goal, we must complete another two official tests and begin the certification of our institutional problem-solvers in September 2016.

Mindblower in its latest (but not final) version will run from October 2016 to July 2017. Then we will apply a detailed evaluation which will include interviews with participants, testing the prototypes and monitoring the project's implementation. We believe that the most important test will be the quality of the prototypes, which we will contrast with the kind of results achieved with other methods.

This model still continues to be tested, refined, reviewed and, hopefully, will be positioned as a trustable and inspiring problem-solving method, compatible with design thinking, TRIZ, logical framework, balanced scorecard, visual thinking, among other useful resources.

In a way, this project transformed the work we do every day with students, business executives, and the general public, in a permanent cycle of prototyping and improvement of a working model of competency-based training.

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Improvised Concept Development Process in Design Through Product Ingredients

Prabhat Kumar and Puneet Tandon

Abstract The success of any product depends on the quality of concepts developed, as per the customer requirements (CRs). It involves an information processing activity, where the information is formulated into a feasible concept. However, it is realized that during any design process, information about the problem is missing at the beginning of the design process. This work identifies that a consumable product may have a minimum of thirty-four design ingredients to define CRs precisely and represent domain information for the designers. The analytic hierarchy process (AHP) is applied to capture the intensity of the requirements by the acquired information. This work presents a systematic method of product design, driven by these thirty-four design ingredients. With product ingredients, a designer can pre-plan intended design space. The primary advantage of the proposed method is to target the required information correctly and quickly, for product design.

Keywords Product design · Concept generation · Product ingredients · Information

1 Introduction

Product development is a process of creating new products to fulfill the customer requirements (CRs). On the basis of inputs gained from Wheelwright [1], Anderson [2], and Ulrich and Eppinger [3], this development process usually includes the design stage like: (i) identifying customer wants, (ii) setting target specifications,

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(iii) concept creation, (iv) concept selection, (v) concept examination, (vi) setting final specifications, (vii) project planning, (viii) economic analysis, (ix) benchmarking of competitive products, (x) modeling and (xi) prototyping. All the stage involves information processing activity, in which designers gather and organize information. The first and critical stage in the design process is the identification of CRs information because from this information whole design process is undertaken. Griffin [4] has discussed the richness of existing literature on CRs, yet inadequate consideration has been paid to how product management and experts are liable for defining the CRs.

Furthermore, it is still not explained clearly about the information desired for product design. Hence, as per the CRs in this work thirty-four design ingredients are presented for the desired information framework for design any product. Identifying customer needs very clearly and accordingly outlining product concepts is a critical step for successful product development. It is reported that designers invest about 60% of their time for the 'right' information [5], and this process is rated as the most baffling part of the design process. On the basis of the available, but limited information, the designer, generates concepts mainly with the help of design research, brainstorming, SCAMPER, concept fan, user narration, descriptive recombination, user creation, brain-writing, problem decomposition, cause and effect trees, etc. These techniques provide many solutions in the product design space. Selection of one concept among "n" number of concepts is a typical task, and the chances of a wrong selection are high. Further, as we have to select only one concept, thus the remaining $(n - 1)$ concepts are responsible for the increase in turn-around time and resources committed. It is imperative that the smart idea is chosen, as it determines the course of the embodiment design stage. Hence, in brief, the objectives of this research can be stated as:

- To identify the required information and accommodate CRs,
- To capture the degree of importance of the CRs, and
- To quickly target the right concept as per the weight of CRs

This work presents a new systematic method for capturing CRs information and accordingly development of conceptual phase of the product design, driven by thirty-four design ingredients. The analytic hierarchy process (AHP) has been utilized to capture the level of significance of CRs. The primary advantage of the proposed method is quick to target the right concept for optimum product configuration. As concept development and selection are the primary steps of a product design process, this work is limited to concept generation phase of product design.

2 Literature Review

Generating, gathering and sharing information, data and knowledge in design have been an underlying theme in the design research and practice for a long time [6]. Nowadays, both manufacturing and service sectors have embraced elaborate variety management and technique to capture the right information related to customer needs. As the design of any product start with CRs and accordingly designer generate product concepts to fulfill these needs. Hence, information related to CRs is very vital for successful product design. Therefore, review presented here is carried out under 'CRs' umbrella.

As per Nishino et al. [7] professional must explicitly observe customer behaviors using accessible information got through services. In spite of the fact that the customer purchase information is a major source to showcase customer attitude for service providers to establish customer desires; such information are inadequate for clarifying customer decision-making procedures including their inspirations, way of life, price opinions, or joy with products or services after usage. According to Chan and Wu [8], numerous methods are existing to collect CRs. They include focus group, personal interviews, listening and viewing, natural field communication, warranty data, feedback and criticisms, affinity diagram, cluster interpretation, etc. As of late, many traditional and trade-based decision making systems for product design have been revealed for making judgments on new product development, including CRs, consumer loyalty, product quality, product design, market demand and pricing [9–13]. Quality function deployment (QFD), which is a tool to convert customer requirement to engineering characteristics, is a long process, mostly analytical and fails to translate the relative importance of CRs into the relative importance of engineering characteristics uniformly [14]. An alternate approach that is widely used in both industry and academia for impressive analysis of CRs is Kano's model, which identifies user requirement and expectation through a preference classification technique [15]. As per Lee and Huang [16], the conventional Kano's model only considers crisp (the inverse to fuzzy) explanations, and thus, ignores the fact that CRs are vague and undefined due to their linguistic origins. The conventional Kano's model not only has the drawback of ignoring the imprecision and uncertainty in CRs but also, it is a qualitative or subjective method based on discontinuous classification criteria. There are reports accessible in the literature on efforts to formulate a fuzzy extension of Kano's model so as to manage the imprecision and vulnerability in CRs [17–19]. Nagamachi developed Kansei Engineering, as an ergonomics and consumer-oriented tool to translate customer perceptions and feelings into form ingredients [20, 21]. It has been effectively applied in the area of product design [22–24] to investigate the relationship between the feelings of the purchasers and the design components of products. Lin et al. [25] exhibited another method for converting users' perception into product elements design, alongside a test investigation of cell phones. This robust design approach enhances quality observation by reducing the discrepancy between the actual customer feeling and the desired feeling, to decrease ambiguity produced by individualistic characteristics of the customers. A statistical technique conjoint analysis is regularly utilized in market research to determine how people value different attributes (requirements) [26]. Most of the design techniques concentrate on technical domains to determine customer needs. However, various challenges exist in CRs identification and collection. Identifying actual CRs involve understanding genuine issues and what products empower customers to do. Acquiring implicit and complex knowledge from customers is laborious, and organizational barriers make it significantly harder [27]. The literature indicates product design can be a challenging task due to information about the problem is missing at the beginning of the design process. Therefore, this work presents a systematic method for capturing CRs information along with design information that is driven by thirty-four design ingredients.

3 Proposed Method

The thirty-four design ingredients are proposed on the basis of extensive study of the work done by previous researchers, Pahl and Beitz [28], Hubka and Eder [29], Pugh [30], Roozenburg and Eekels [31]. It is noted that a consumable product may have a minimum of thirty-four design ingredients, as shown in Table 1 column 2nd "Ingredients". With the aid of proposed information framework thirty-four design ingredients, the necessary information required for the design process can be accumulated early during the design process. The purpose of introducing these ingredients is to capture the CRs in a lucid manner, as the requirement can be fragmented in terms of design ingredients. However, in literature, a few fuzzy models are proposed, if the information is fuzzy in nature. Among the various techniques available for information collection, this work uses interview technique to gather the required information about thirty-four design ingredients. The reason behind the choice of the interview is due to its cognitive approach and immediate availability of the required data for the desired application. In the reported work, random interviews were conducted among the university students and some other users due to the choice of the product (bed study table) to validate the method. After the first phase of the interview, which was generic in terms of thirty-four design ingredients of the product, later, the questions specifically addressed customer need identification. The analysis was directed by utilizing the subjective technique of reading the interviews many times to discover actual CRs information and noted in Table 1. All the significant CRs having an impact for the product design is accommodated. As it is not possible to fulfill all CRs, therefore, to address this issue, analytic hierarchy process (AHP) is utilized to decide the significance CRs [32].

4 Implementation and Validation

This section presents the implementation of the proposed method and develops an optimal product design concept for a test case. The motivation behind selecting bed table as a case study and presenting in this manuscript is due to its simple structure and easy functionality. Effectively capturing and analyzing customer requirement regarding bed table is a challenging task. To collect CRs information, the technique used in this work is an interview, with respect to thirty-four design ingredients. With the aid of proposed design ingredients, the necessary information required for

Table 1 Thirty four proposed design ingredients for the bed table

No.	Ingredients	Customer perception	Articulated CRs	Definitive CRs
1.	User	Using a laptop on bed or for reading/writing on bed	Design for students, Professionals, etc.	User friendly adjustable, portable
2.	Performance	Convenience of usage	Comfortable	Usability, accuracy
3.	Temperature range[a]	N/A	N/A	–
4.	Pressure range[a]	N/A	N/A	–
5.	Humidity	The material should not be effected by the humidity	Material choice	Rust free material
6.	Shock loading	Capable to withstand weight of laptop, books, etc.	Weight of laptop/books	Robust material
7.	Dirt or dust—how dirty?—how clean?	Bedroom, normal dust	Bedroom dust	Modular design—easy to clean
8.	Corrosion from fluids/chemical	If any fluid drops on table, the product should not be effected	Corrosion inhibitors are often added to paints	Rust free material
9.	Vibration	Unbalanced rotating components	Close-fitting	Least tolerance
10	Hazards[a]	N/A	N/A	–
11	Environment[a]	N/A	N/A	–
12	Maintenance	As minimum as possible	Minimum maintenance	Modular, redundancy
13	Market competition	Available in low-cost	Not portable, low quality material	Economic
14	Packaging	Should not be damaged during transportation	Plastic packaging	Shock proof packaging
15	Quantity	Not all customers use it	Less	Lean
16	Manufacturing facilities	Top of the board should preferably be textured, so that a book or laptop has minimum chance of slipping, if any joint, should be invisible	Wooden table	Design for manufacturing

(continued)

Table 1 (continued)

No.	Ingredients	Customer perception	Articulated CRs	Definitive CRs
17	Length, width and height	Easy to use, reach and keep	Ergonomic established dimensions (50 cm × 30 cm × 22 cm)	Standard parametric design
18	Aesthetics, appearance	Should have cool look	Sleepy mood	Colour, texture, symmetry
19	Materials	Low weight, good strength	Portable	Wooden
20	Product life span	Throughout the schooling	Requirement	Robust/redundancy
21	Standards and specifications	More than competitor	Competitor benefits	Standards parts
22	Ergonomics	Comfort	Relief	Anthropometric
23	Customer	Students, young professionals	Load of work	User friendly
24	Quality and reliability	Moderate	Simple function	Modular, redundant
25	Processes	Wood work process	Wood work	DFA
26	Testing	Comfort, ergonomics	Comfort on the bed	–
27	Safety	Posture	Comfort	Sharp edges
28	Company constraints	Cost	Competitor	–
29	Market constraints	Product cost, access to the product and effective promotion	Profitability	–
30	Patents, literature	Design	–	–
31	Legal	Pollution, disposal, legal policy	Government norms	–
32	Installation	Simple	Easy to use	–
33	Documentation	Manufacturing process, sketch, assembly	Easy to understand	–
34	Target product cost	~US$ 20	Competitor	

[a]Not applicable (N/A)

Table 2 Pairwise comparison values

Criteria[a]	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6	CR_7	CR_8	CR_9
CR_1	1	2	4	2	1	1	3	1	2
CR_2	0.5	1	1	4	1	2	0.33	0.5	1
CR_3	0.2	1	1	4	2	3	2	1	2
CR_4	0.5	0.25	0.25	1	0.5	0.25	0.33	0.5	0.25
CR_5	1	1	0.5	2	1	1	0.25	1	1
CR_6	1	0.5	0.33	4	1	1	1	1	1
CR_7	0.33	3	0.5	3	4	1	1	1	1
CR_8	1	2	1	2	1	1	1	1	1
CR_9	0.5	1	0.5	4	1	1	1	1	1

[a]CR_1: foldable, CR_2: shock loading, CR_3: adjustable, CR_4: easy to clean, CR_5: aesthetics, CR_6: ergonomics, CR_7: vibration, CR_8: safety, CR_9: cost

any design process can be conveniently accumulated, as shown in Table 1. After analyzing the CRs (Table 1), it is observed that some requirements are very dynamic and can influence the customer as well as the design. All these important CRs having impact for the product design are following: foldable (CR_1), shock loading (CR_2), adjustable (CR_3), easy to clean (CR_4), aesthetics (CR_5), ergonomics (CR_6), vibration (CR_7), safety (CR_8), Cost (CR_9). For the proposed case study (i.e. bed-table), a variety of requirements are mentioned by the customers and it is not-possible/beneficial for the manufacturer to satisfy the entire set of requirement with equal importance. Therefore, the next step determines the degree of importance of CRs through AHP.

For each CRs, pairwise comparisons are quantified by using a scale of 1–9 as per Saaty [32]. Pairwise comparisons are the well-recognized method of multi-criteria decision making [33, 34] and an effective way for eliciting qualitative data. The pairwise comparisons used in this study are shown in Table 2.

After normalizing the pairwise comparison values of Table 2, the summation of normalized values of each criterion provides the weight of CRs as shown in Table 3.

The next phase is to generate concepts for the bed table in line with the requirements of the design element as shown in Table 1. Careful consideration of CRs weight, and accordingly proposing the concept would yield higher profit and competitive advantage to the company. For the proposed case, the primary objective function or maximum weight among the expectations of the customer is of "foldable" (weight of importance: 0.18278618). Therefore, this was considered as the most important technical requirement that needs to be improved first. One probable solution to address this is to use the hinge. The second most important factor was found to be "adjustable" (weight of importance: 0.14786853), which after lengthy discussions, was addressed by providing adjustable legs through adjustable leg screws or crutch. Accordingly, the weigh customer expectations (Table 3) are addressed.

Table 3 AHP weights of customer requirements

	Customer requirements (criteria)	AHP weights
CR_1	Foldable	0.18278618
CR_2	Shock loading	0.09812239
CR_3	Adjustable	0.14786853
CR_4	Easy to clean	0.03917689
CR_5	Aesthetics	0.0888433
CR_6	Ergonomics	0.09903246
CR_7	Vibration	0.13475934
CR_8	Safety	0.11282479
CR_9	Cost	0.09658613

Based on the identified ingredients, it is advised that the designer should generate and select the best idea to satisfy the product ingredients having high weight first. For example, for the bed table, the priority are foldable, adjustable, vibration, safety, ergonomics, shock loading, cost, aesthetics and easy to clean. If required the evolved concepts may be refined. This may involve the designer solving an unworkable part of the solution. Once the design concept meets all of the functions or product ingredients, the concept is ready for product architecture phase. It would be easy to evolve effective, manufacturable and feasible concepts.

Fig. 1 Working prototype for user study

5 Results and Discussion

The proposed method provides a systematic way to capture customer requirement and, to convert requirement into concept on the basis of sound technical knowledge and information. Figure 1 shows working prototype for the user study and demonstrates the product usage. This method transforms the design process from a creative activity to a systematic decision-making process and helps in evolving the most optimal concept design. Analysis of design ingredients (as shown in Table 1) allows the designers to be efficient and yet comprehensive in determining proper design choices as per the customer requirement. With the aid of customer requirements weight, maximum customer expectations are addressed in the proposed concept.

6 Conclusions

Identifying, understanding and meeting the customer expectations correctly are very important for product development. Precise and effective considerations of customer expectations, and accordingly improving products and services yield higher profits and competitive advantages to the companies. For the success of any product, the evolved concepts should aspire to meet maximum customer needs. This work reports a new systematic framework to capture customer requirements to generate concepts within optimal design space. The proposed thirty-four design ingredients define customer requirements precisely and represent domain information for the designers. However, the success of the method greatly depends on the implementation, which in turn depends on the customer inputs and the designer experience. If the conditions are fulfilled, the proposed method becomes a powerful tool for the designer, which provides a strong support in the process of new product design as per the customer expectation.

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Influence of Creative Thinking and Playfulness on Creative Styles of the Individuals

Mritunjay Kumar, Satyaki Roy and Ahmed Sameer

Abstract This study was done to understand the influence of creative thinking and playfulness in enhancing creative self-esteem of students. 40 freshmen master's students in the Design discipline, participated in the study. Participants were required to undergo an activity involving creative thinking and playful activities. Their creative self-assessment was carried out using creative style questionnaire-Revised (CSQ-R), pre and post activity. Results did not indicate a global increase in creativity of the students as assessed by CSQ-R. However, two subscales of CSQ-R viz. Use of other people ($p < 0.001$) and Environmental Control/self-regulation ($p = 0.04$) showed significant change post activity. The findings are discussed in light of cognition research. We argue for design and implementation of such creative thinking based workshops in enhancing the creative styles of individuals especially through improvement in working with groups and self-regulation of the individuals.

Keywords Creativity · Creative assessment · Creative thinking · Creative activity · Creative workshops · Creative enhancement · Creative style questionnaire-revised

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1 Introduction

Creativity is a well-researched topic and various disciplines use varieties of definitions, theories and approaches. A comprehensive definition of creativity says "it's an interaction encompassed by multiple attributes e.g. the environment, aptitude, the process and the individuals or group that achieves a novel and useful perceptible product suitable in the social context" [1]. Indeed creativity is one of the complex and multifaceted attribute required by individuals. Creative thinking is a necessary element for the individuals facing the challenges of the competitive world where demands are high. As once Einstein said "You can never solve a problem on the level on which it was created." This clearly indicates the need of shift to creative thinking where the problem needs to be sensed differently.

Various factors contribute to the development of creativity. Guilford [2–4] saw creativity as a collection of various complementary components (cognition, memory, convergent thinking, divergent thinking and evaluation). Creative people often engage themselves in various activities (a) collaborate and share their ideas with somebody else to be creative (b) influence from the external factors to facilitate their creativity (c) brainstorming techniques to generate multiple ideas [5]. Personal characteristic of an individual and creativity are also related. Amabile [6] suggest that motivation (intrinsic and extrinsic) helps improve the creative potential of the individuals who are motivated to work with rational playfulness. Individuals experience joy and thus are motivated to engage themselves in the learning process and other activities during the process of playfulness. Playfulness has a beneficial effect on creativity and Innovation.

Today fostering of creativity is one of the major target for the primary education for different countries in the world. The present education system comparatively emphasize more on the examination based patterns as compared to the real learning in classrooms [7–9]. Goodale also argues that the traditional examination pattern hampers the growth of creativity since they only require limited memory associations and divergent thinking process [10]. Education committees and commissions in India have frequently criticized the Indian education system where they fail to foster creativity amongst the Individuals [11]. G.S. Sharma and Mandal also reported that the Indian education system is struggling to endeavor creative abilities amongst the children which is essential for their futuristic success and prosperity [12]. Hence education system must not only focus on the development of intelligence but also on development of creative expression.

1.1 Playfulness and Creativity

Playful activity is characterized by positive mood behaviour which elicits creativity, or helps in generating novel solutions to a problem [13]. Playfulness and creativity are linked together where play helps to generate novel ways to deal with the existing problems. Playful activities require imaginations which utilizes individual's previous memory associations. Breaking the established patterns, thoughts or behaviours are the major characteristics of a playful activity. Play activity features are best suited to find the appropriate way in the conflicting situations without worrying about the real time challenges. The rules can be broken, results are spontaneous and individuals get intrinsically motivated to perform a task [14]. Individuals discover new approaches and methods to deal with the challenges through play. Also previous memory associations help improve creativity. People who are open to new experiences are found to be more creative.

Another characteristic of play is that it enhances individual's knowledge and behavioural repository, making it more flexible to adapt to new conditions. However, playfulness might not appear to output immediate goals or benefit. Rather the experience gained from these playful activities helps the individuals to perform better in the later stages of life.

The design of Foldit [15], protein folding game is one good examples of complex creative problem solving through crowdsourcing. Foldit attempts to solve the complex protein folding structures by the participants all over the world through a computer based interface. The folding part is highly intuitive and high scored solutions are analyzed by the researchers to be applied in the real world. Such kind of creative thinking based playful activity can certainly contribute in unlocking the unsolved mysteries regardless of domain specific knowledge. However, playfulness and creativity in computer based games is another huge research area which needs to be explored in depth.

Training courses provided to the individuals certainly have established some degree of success in fostering creativity [14]. Major objective of this study was to see that playful creative thinking facilitates creativity amongst the individuals. We encouraged individuals to work together in groups, share their experiences and knowledge ultimately affecting their creative style. *Creative style* refers to the approach or strategy when trying to solve a problem [16]. Diversity of the student encourage creativity and the multidisciplinary approach of the design discipline will help generate new ideas. This idea is well supported in literature [14] where they say more creative ways will arise when people interact with each other rather than working in isolation. Personal interpretation of playfulness significantly influence creativity [17]. The aforementioned literature indicates the relationship between creativity and playfulness. However, having less scientific research done in this area to identify what people do to be creative? What process they adapt to be creative? We propose the following hypothesis which tries to identify the creative process that individuals take to be creative when engaged in playful activities.

Hypothesis—Creative thinking playful activity influence the creative styles of individuals.

2 Method

2.1 Participants

This study employed 40 freshmen students from the design discipline, 29 males and 11 females, (Mean age = 24.6 years, SD = 2.3) from a technical Institute who voluntarily participated in the study. The participants joined the Institute for their Master of Design degree programme after clearing the CEED (common entrance examination of design, India)[1] entrance examination, written test and interview. The students can be perceived to some extent as creative individuals as they cleared all India competitive examination for design (CEED). They were a part of the design course module which was being offered in the Institute. Participant's background varied from Civil engineering, Computer Science, Aerospace engineering, Mechanical Engineering, Electrical engineering, Architects and Fashion Designers. 40 participants were divided in 8 groups having 5 members in each group randomly.

3 Materials

3.1 Creative Thinking and Playful Activities

The course blended a mix of playful learning with basic theory on the design thinking (how to solve a problem). The course was organized into 3 modules for a period of four months. 1st module only focused on the theoretical part of the design thinking process. 2nd module focused on the playful activities done in groups and the 3rd module consisted the prototyping phase (tinkering with various materials, developing various forms). Course variety included repeated brainstorming sessions, group playful activities etc. In this paper we specifically present the 2nd module for its direct relation with creativity and playful activities.

6 playful games were used for the students.

- **Game 1: Fit inside the circle**

All 40 students had to fit inside a 15-in. radius circle marked on a ground. They had to fit inside the circle with a nice form. After each successful attempt the circle size got reduced by 2 in. Figure 1 shows the game played by the students.

[1]CEED—Common entrance examination for design is a national entrance examination for post graduate studies in the field of design. This examination is hosted annually by the Industrial design Center, IIT Bombay on behalf of MHRD, Govt. of India.

Fig. 1 Participants playing the game 'fit inside the circle'

- **Game 2: Reach the other side alive**

Participant groups had to imagine a scenario where there was a chemical apocalypse that has happened in a factory and the only way to survive the situation was to reach the other side of the chemical infected area. Participants were provided few newspapers which could only be used as a medium to reach the other side. Group reaching the other side first, wins the game.

- **Game 3: Make the longest tower**

Participant in groups had to make the longest tower only with the help of few newspapers, glue and paper cutters within a fixed time constraint. The group who makes the longest tower wins the game.

- **Game 4: Sinking boat. Whom will you save?**

Participants were given an imaginary situation where each one of them will play a typical character from the real life, for example—An engineer, President of India, A differently abled person etc. Scenario—All 40 characters are in a sinking ship where they can only save 10 people due to the limitation of the life boats available in the ship. The challenge was to choose the appropriate person.

- **Game 5: Imagine a space and illustrate the elements.**

Students were asked to imagine a space, for example—Economy section of the airplane, a lecture room etc. Students were then provided with a piece of paper with 25 blank frames and were asked to illustrate individual elements from that imagined space on the blank frames provided, for example—(table, chair etc.).

- **Game 6: Metaphorical thinking**

Students were asked to find analogy between an umbrella and a turtle and were asked to conceptualize an umbrella for disastrous situations.

3.2 Format and Structure of the Games

Our designed games help the individuals to be more creative in their approaches when solving a problem by:

1. These games involve the process of divergent thinking with an open choice approach. Individuals can freely assimilate (*think new ideas or imagination*) and accommodate new schemata to solve the problem of each game.
2. These games involve the peer discussions and collaboration which helps in the process of divergent thinking. Individuals try to judge their attitude and approach when working in groups. Individuals also empathize towards the other group members (*understanding their emotions*).

3.3 Ratings

To assess the creative styles or approach of the participants, CSQ-R (creativity styles questionnaire revised) [16] was used pre and post course module. CSQ-R is a self-measure and reporting scale consisting of 78 items which targets the participant's beliefs, approach, procedures and environmental control used to expedite creativity in their lives. Kumar et al. [16] also suggested that this self-rating questionnaire can help the individual to understand their creative tendencies which can later be then modified or improved as per the context and need. The CSQ-R is measured within eight subscales or local measures: (a) Belief in the Unconscious processes (contains 17 items) assess the participant's intrinsic beliefs about being creative (e.g., "I feel that new ideas possess me and guide me through to completion almost automatically"), (b) Use of techniques (contains 18 items) indicate augmenting creative skills with specific strategies or any techniques (e.g., "I am always thinking/fantasizing about how to do everyday things differently"), (c) Use of other people (contains 9 items) illustrates the collaborative approach of the individuals who consult, share their ideas and work with other people (e.g., "I am at my creative best when I work in a group"), (d) Final product orientation (contains 7 items) focused on the extrinsic motivation of the individuals towards the final product (e.g., "I think a final product that is not readily observable through the senses can emerge in a creative act"), (e) Environmental Control (contains 18 items) focused on the influence of various stimuli existing in an environment to self-regulate and facilitate creativity (e.g., "I reward myself in some way after

I have worked on my creative idea (s) for a designated period of time”), (f) Category superstition (contains 2 items) assess the superstitious beliefs and practices to facilitate creativity (e.g., “I have a favorite tool—a certain pen/easel/ thinking cap, etc. without which I would find it hard to concentrate when I am engaged in creative work”), (g) Use of senses (contains 5 items) emphasize the use of all the five senses to be creative (e.g., “I tend to use my sense of touch a lot in my creative work”). Participants rated each subscale questions on a these values—1 (Strongly agree), 2 (Agree), 3 (Unsure), 4 (Disagree) and 5 (strongly Disagree). Each subscale ratings were totaled to give separate subscale scores.

4 Procedure

Before beginning the 2nd module, participants were asked to fill the CSQ-R questionnaire. This was done to record the existing mindsets, beliefs, strategies and techniques towards being creative. Course was conducted twice a week which ran for a period of 4 weeks and each game was played by the participants within a duration of 30–45 min. Participants were provided with all the necessary tools as per demanded by the game rules. Participants either performed these playful activities individually (*game* 5 and 6) or in groups (*games* 1–4). All these activities were performed on an open terrace (66 ft $\times$ 48 ft) wider space to accommodate 40 students for various activities. After each activity participants were asked to submit a report with a refined version of the solution in a notebook within 2 working days for evaluation. Participants were instructed to fill the CSQ-R questionnaire after the 2nd module was over to evaluate the difference and impact of these playful activities on being creative on various subscales.

5 Results

This study examined the change in the creative style index of the individuals on various subscales. The results were analyzed using the repeated measures, Tukey—HSD analysis was done and the results were found highly significant for the subscale *the use of other people* ($p < 0.001$) and found significantly high for *Environmental control/Self-Regulation* ($p = 0.04$). Tables 1 and 2 show the significant improvement found in the two subscales. Table 3 summarizes all the ratings of the CSQ-R on various subscales. We also examined the overall change which showed no significant differences. The results revealed a greater engagement and performance in the creative activity when participants worked in groups. We observed an initial repulsion amongst the individual to share or discuss the idea amongst them but eventually the fear of rejection got subdued once the participants were instructed to be open to the weirdest or the wild ideas. Think aloud protocol was used in each group to come up with multiple solutions. Further, participants

Table 1 Summary of repeated measures ANOVA for the subscale (*use of other people*)

Within subjects effects_other people						
	Sum of squares	df	Mean square	F	*p*	η^2
Other people	45.276	1	45.276	349.2	<0.001	0.9
Residual	5.057	39	0.13			

Note Type III sum of squares

Table 2 Summary for repeated measures ANOVA for the subscale (*environmental control and self-regulation*)

Within subjects effects_self regulation						
	Sum of squares	df	Mean square	F	*p*	η^2
Self-regulation	0.002	1	0.002	4.333	0.044	0.1
Residual	0.022	39	5.585e−4			

Note Type III sum of squares

Table 3 Ratings of all the subscales of CSQ-R (*pre and post activity*)

Subscale	Pre-activity (mean score)	Post-activity (mean score)
1. Belief in unconscious processes	52.82	52.95
2. Use of techniques		
3. Use of other people	59.87	59.87
4. Product orientation	27.5	27.47
5. Environmental control/self-regulation	19.55	19.65
6. Superstition	48.55	48.35
7. Use of senses	4.6 16.05	4.725 16.02

also self-regulated themselves to facilitate their creative work during this course i.e. they used external stimuli to facilitate their creative process (music, consumption of snacks, assigning a particular place for the creative work). This result suggests the influence of playfulness on the usage of external stimuli to self-regulate, or facilitate creativity.

6 Discussion

Although vast literature exists regarding the relationship of playfulness and creativity, very few literature discusses the impact of playfulness on creative styles of the individuals. Our paper identifies the major creative styles used when people are engaged in a playful activity. Playful activities certainly help improve creative styles of individuals. This is in conformity with the earlier literature [6, 14, 18] which discusses influence of playful activities in enhancing creative esteem of the individuals. The evidence indeed showed that working in groups was found to be more facilitating in generating ideas than working individually. Playful activities, especially when performed in groups helps to re-channelize individual's collaborative tendencies and their approach in using external stimuli to facilitate creativity. Playful activities should be carefully designed which will ultimately help the individuals to identify their other creativity styles which has not been found significant in this paper.

Playfulness can enhance the motivation of individuals to be more involved in the task rather than leaving or getting frustrated with it. Playful creative thinking can also be beneficial in terms of motor skills and social interaction ultimately affecting the well-being of the individuals. Results suggest the implication of positive, playful mood and creative thinking helps in fostering creativity. Organizations who are concerned with generating new ideas, new discoveries generally require multiple skillsets and we think creative thinking and playfulness are the mediums which should be adapted to meet those requirements. Intrinsically motivated individuals perform better [6] and playfulness provide a new way to challenge and find a novel solution which fulfills as a sufficient reward. It has also been found that people tend to work harder and perform better when driven by intrinsic rather than extrinsic motivation [14].

However, the role of environment and tangible tools with which we interact should also be considered when creative playful activity is performed. The degree of playfulness might also differ in the context in which it occurs. Individual differences such as personality traits and behavioral styles also plays a major role when determining a creative output. More research is needed to reveal exact nature of influence of playful activities on creativity.

Putting these results and earlier findings together we can conclude that creative play involves freedom, fun and breaking the rules and this perspective might be helpful to analyze cognitive skills that can be used in later stages of life specially when solving the complex real world problems. Academic achievements can be fostered by motivating such creative thinking workshops where playful learning environments can be used as a tool in the conventional forms of learning. These type of activities can help the individuals to identify their present style of creative process and act as an insight to modify their attitudes or make them into the right mindset of being creative. People must realize the complexity of a creative process.

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Idea Inspire 3.0—A Tool for Analogical Design

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Abstract There is a continuous demand for novel and innovative products in the market. In order to develop novel ideas, natural systems are considered to be superior source of inspiration. In order to assist designers in ideation, an analogical design tool called Idea Inspire 3.0 is developed; it is a revised version of Idea-Inspire developed in 2005. The latest version is web-based, and supports retrieval, visualizationand addition of systems. It uses a novel, dynamic representation with amulti-system, multi-instance SAPPhIRE model as basis, and a multi-modal explanation for enhanced understanding that shouldlead to better ideation. In this paper, these latest features of Idea-Inspire along with their potential benefits are discussed.

Keywords SAPPhIRE · Analogical design · Bio-mimetic design · Multiple-instance model · System representation

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1 Introduction

There is intense competition among products in the market. Since existence of a product is temporally limited, there is a need for designers continue to innovate products [1]. Analogical reasoning is vital in developing ideas for new products [2]. Most often, these ideas are inspired from the artificial domain since their designers are familiar only with this domain [3]. However, research indicates that ideas inspired from more distant domains such as nature are likely to be more novel [4].

A variety of products has been developed using ideas from nature, e.g. Velcro was inspired from burrs [5]; the shape of 'Shinkansen' train was inspired from the beak of a Kingfisher [6]. Inspiration from biological systems offer several advantages [7]. Firstly, biological systems utilize minimal amounts of energy and resources [8]. Secondly, biological systems are adaptable to variable external conditions [9]. Thirdly, they are environmentally sustainable [10]. Further, they are self-regulating intelligent systems [9]. In addition, they are capable of self-assembly using processes like synthesis, reproduction and succession [11]. Hence, nature is a potential source for inspiration for developing novel products [12]. In order to provide inspiration with which to trigger ideation, a tool needs to be developed for retrieval and visualisation of systems (as inspiration) from the biological domain. Further, the tool should support users share their knowledge of biological systems by adding these into the database, so that the database can progressively expand to support better ideation.

In order to utilise information about biological systems for new product ideation, the user needs to understand these systems [13]. Due to knowledge gap, comprehending biological information is usually a challenge for engineers [14]. A comprehensive approach involves understanding all sub-systems that constitutes a system [15]; the sub-systems themselves can aid ideation. A representation needs to be developed, for both systems and sub-systems, that could help designers retrieve and understand systems [16]. Usually, systems are explained using text. However, other modes of representation, e.g. images and videos have proven to assist in novel idea generation [17]. Hence, a multi-modal representation for systems/sub-systems is necessary.

The tool that we intend to develop needs to support the following: (i) *retrieval* of systems from the biological domain; (ii) *understanding* of these systems for ideation; and (iii) *addition* of further systems into its database by its users. For these, developing an appropriate, multi-modal representation for systems/sub-systems is necessary.

1.1 Background

Analogical design has been a major source of support for enhancing creativity in design [18]. Many tools have been proposed to aid in this process, but with a variety of limitations. Firstly, some of these tools provide a vast number of results as inspiration, many of the results are not relevant. Secondly, the language used in such tools is often highly domain-specific, which makes it difficult for a non-biologist to understand [19]. A few of the major tools are reviewed below.

TRIZ (Theory of Inventive Problem Solving) is a suite of approaches towards problem solving (system development), conceptualized over reduction of engineering contradictions, which happen when increase of one parameter in a system causes decrease in another. From Altshuller [20] and Domb [21] a definitive set of 39 contradiction features were juxtaposed against one another in a contradiction matrix, from which conflict pairs could be obtained. Each of the conflict pairs are matched with the ones in existing, solved problems in order to retrieve an analogy, which in turn would act as a hint in to solve the current problem. This idea was utilized in by Vincent et al. [22, 23], which led to development of BioTRIZ matrix. Instead of 39 contradiction features, BioTRIZ matrix holds six fields: substance, structure, space, time, energy, and information. This work makes use of a System Operator, which is a 3×3 matrix for the object (component or system) under consideration. Vertically, the operator represents a hierarchy of 'Super-system', 'System', and 'Sub-System'. Horizontally, at each level of the hierarchy, time is represented using 'Before', 'Now' and 'After'. The Term-Patent Matrix, similar to contradiction matrix, was developed for PAnDA (Product Aspects in Design by Analogy), for patent retrieval to support analogical design [24].

Idea-Inspire was the first searchable, computational repository of biological systems for supporting bio-mimetic and biologically inspired design. Developed in 2005 by Chakrabarti et al. [25], the tool aids in synthesis of novel designs by drawing inspiration from over 1200 natural and artificial systems stored in a database. Each system is described using two representations, along with images and videos: one based on FBS [26] model, and the other using SAPPhIRE model. SAPPhIRE model evolved as an integration of, and therefore has been argued to be richer than, various other models in literature such as those in FBS [26], SBF [27], Domain Theory [28], Theory of Technical Systems [29] and Metamodel [30]. The constructs are decomposed into Verb, Noun, and Adjective according to SAPPhIRE model and used as search criteria for retrieval of systems. Idea-Inspire was the first tool that supported addition of new systems into the database. However, the tool was standalone; the design solutions added by one user could not be reused by other users. Further, each system is represented using only a single SAPPhIRE model instance, irrespective of the complexity of how it functioned.

AskNature, a web-based tool introduced in 2008 [31], has a repository of over 1600 biological strategy pages. It is a web-based platform where engineers and biologists can collaborate and form a knowledge network. The database is categorized according to taxonomy with the following constructs: Group, Subgroup, Function, and Strategy. In a systematic search, the user selects one group of strategies, converges to a sub-group and obtains a list of functions [32]. However, the level of detail provided on each system is not extensive. Further, users often practise traditional, keyword-based search instead of using the taxonomy provided.

AskNature does not provide any facility for users to add new systems into the database.

Introduced in 2012, DANE [19] is another tool for providing biological stimuli in design problems; it is based, among others, on a study conducted on biologically inspired design [33]. The tool works with a database that houses nested SBF [27] (Structure—Behaviour—Function) models of natural and engineered systems. A nested model is represented using nodes (systems) connected across systemic levels and edges that indicate hierarchical relationships. DANE, similar to Idea-Inspire, supports addition of new design solutions by its users [19]; however, studies conducted on DANE shows that it is difficult to add data using this feature; it is also stated that the SBF models were incomplete in most of the systems added in the database. The systems are hierarchically linked with one another to represent systems that are more complex. However, the connectivity between such systems is lost. The reasons behind incomplete SBF models and inadequate hierarchical representations are as follows: Firstly, the database for the tool is populated using a set of students who have less or no experience with biological systems or SBF representations to carry out efficient system decomposition and construct knowledge-rich models. Secondly, a hierarchical model is not sufficient to represent a highly convoluted biological system, in which events occur sequentially and simultaneously across several systemic levels to achieve an intended functionality. Since it is a standalone tool, sharing of design solutions from elsewhere is not possible, and hence the enormous opportunity for crowd-sourcing and knowledge multiplication is lost. Later, Baldussu [34] used a combination of SAPPhIRE model and DANE representations for synergic benefit.

In summary, the limitations of previous work have been the following: results are not specific to the design problem and hence, compromise *relevance*; the representations lack the desired level of systemic *detail*; except for in Idea-Inspire, *digital-support* like audio, images and videos are largely absent; standalone tools do not support *sharing* of systems across the WWW. To overcome these limitations, a thoroughly revised version of Idea-Inspire [25]—Idea-Inspire 3.0—has been developed.

2 Methodology

2.1 Multiple Instance, System-Subsystem Model

The systems included in the database of Idea-Inspire 3.0 are structured according to the SAPPhIRE model [25] of causality. Modelling is carried out by experts from the biological domain who possess richer knowledge to provide adequate system detail. As discussed earlier, the model provides a richer description of the functionality of natural and engineered systems. Many systems can be represented using a single instance of a SAPPhIRE model. However, complex systems that demand greater levels of description require more than one SAPPhIRE model for representation. Such systems are represented as a combination of simpler structures and functionality. Hence two additional representational aspects are introduced: a system-subsystem hierarchy [35], and combination of multiple-instances of SAPPhIRE model.

Simplification of Systems

In this work, systems are classified as biological or artificial; they differ in the nature of their complexity. Artificial systems are built using components that are assembled to form the whole structure; the components exist at different systemic levels and carry out one or more functions. On the other hand, natural systems are more complex: in general, the number of components present in these systems is greater and their associated functionalities are more elaborate. Functionalities are intertwined with a large number sub-functions occurring sequentially as well as simultaneously [36]. Hence, in order to get a sufficiently rich explanation, it is important to simplify a biological system based both on its structure and functionality. Structural complexity is captured using the System-subsystem hierarchy, and functional complexity using a combination of multiple SAPPhIRE instances. Below, two examples are used to illustrate the representation proposed: single-phase induction motor from the artificial domain, and the soaring of albatross from the biological domain.

A single-phase induction motor, (Fig. 1, left), has a stator, a rotor and a centrifugal switch. Initially, within the stator, a lead in voltage is established to produce a magnetic flux, resulting in a fluctuating magnetic field. In the rotor, induced electromotive force produces a net torque that in turn generates mechanical power. The centrifugal switch disconnects the auxiliary winding. Soaring of an albatross (Fig. 1, right) is governed by three, major, simultaneously acting phenomena: *dynamic soaring* enhances the wind gradient; the tubular nose of the Albatross *senses*

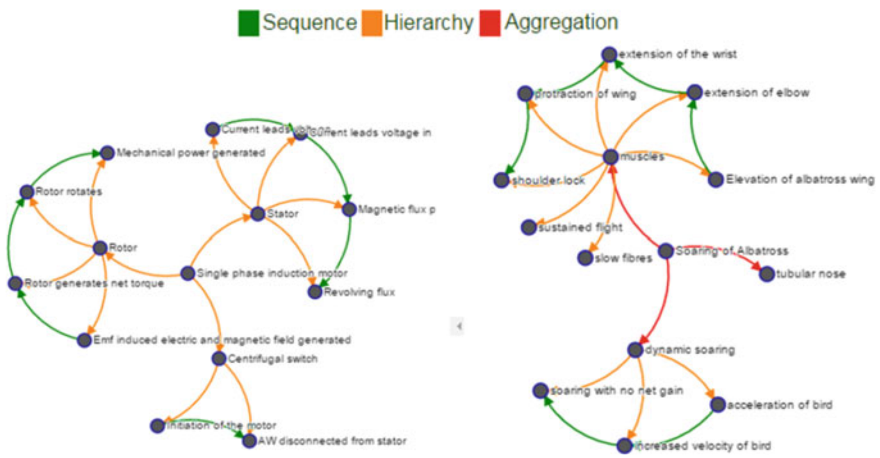

Fig. 1 Model of induction motor and soaring of albatross

pressure difference; the varied muscle composition of the bird engages *shoulder lock* for controlled flight. Each phenomenon is further decomposed into sub-actions.

Multiple-Instance, Multiple-System SAPPhIRE Model
A multiple-instance, multiple-system SAPPhIRE model combines several SAPPhIRE instances; the instances sit at the same or different systemic levels (Fig. 1). The types of links present in a multi-instance SAPPhIRE model are as follows:
Sequential link: As in [37, 38]—*sequential links* combine two events occurring sequentially. Using this link, two SAPPhIRE instances are linked in a sequence in which the *action* of one becomes the *input* for the other.
Aggregation link: Multiple events occurring at the same time are called parallel links [37]. In our work, some SAPPhIRE instances act simultaneously to provide the output for a higher-level system, and are connected using an *aggregation link*.
Hierarchical link: Brown and Chandrasekaran [39] propose that task/function/system is a hierarchical collection of sub-systems starting with the overview of the entire system and later narrowing down to specific parts or components. Following the same ideology¸ a system and its sub-systems are connected using *hierarchical links*.

The multiple-instance, multiple-system SAPPhIRE model is an evolution of the previous version [25] that supported only single instances. The size of the hierarchy of a complex system is not limited, unlike in [22], [32]. In contrast to DANE [19], the model uses any number of sequential and aggregation links at any level of the hierarchy to provide a richer description of a system without losing information on its connectivity. A multiple-instance, multiple-system model could be simplified to generate several instances, each residing at some systemic level. Hence, a system could not only be decomposed into elemental units, but also used as a building block for more complex systems. The tool supports both features.

3 Development of the Tool

Idea-Inspire 3.0 is a web-based tool that allows users access and ideation using the tool from anywhere. Our aim is to support a knowledge sharing network, where users can *browse* the tool for systems in biological and artificial domains to *understand* these, *develop* novel ideas, and *add* new systems to the database that could help in subsequent ideation, by the same as well different users.

The tool has been coded in PHP and JavaScript. Hence, the tool would run in any internet-accessible computer, without the need for plug-in. Systems are retrieved from a MySQL database. Retrieval is fast and secure unlike in other platforms that use SQLite. In the following sections, the features of the tool such as retrieval, representation and addition of systems are explained. The tool also supports other features like blog, verification and authentication (but not discussed in this paper).

3.1 Retrieval of Systems

Systems with potential for stimulating ideation for solving a given problem are retrieved from the database using a parameter based search, based on the design requirements provided by users based on the problem. As shown in Fig. 2, the parameters provided by the users are: Action (verb), Action (noun), Action (adjective), State change, input (noun), Input (adjective), Physical laws governing the system, Components (noun) and Components (adjective). These parameters constitute the various aspects of the functioning of a system, and are in alignment with SAPPhIRE constructs. In view of ARIZ methodology, this retrieval feature allows the designer to decompose the problem and obtain the specific requirements (parameters), which in turn act as search criteria.

The search algorithm is similar to that in the previous version [25]. However, search parameters in the current version are linked to WordNet [40] database, a feature similar to that in [24]. The requirements entered by the user are compared with the descriptions of systems in the database. For capturing their synonyms, the

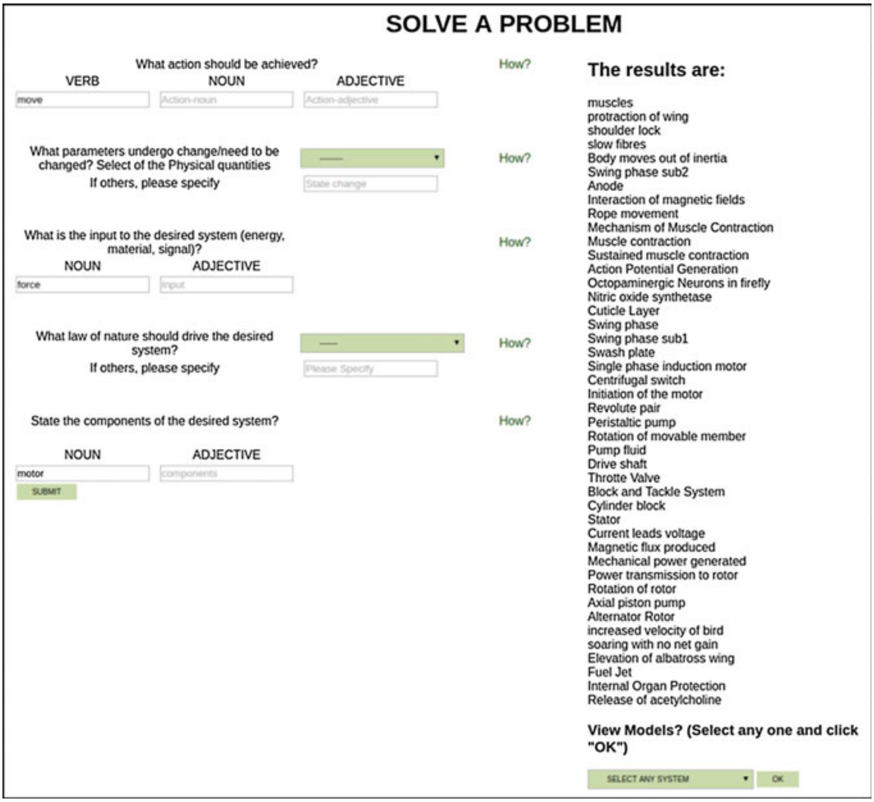

Fig. 2 The retrieval feature in Idea Inspire version 3.0

entries are further searched in WordNet; the synonyms captured are also compared against the descriptions of systems in the database.

An example: A problem as a set of requirements as provided by the user, would be as shown in Fig. 2: Action (verb)—move, Input (noun)—force and Component (noun)—motor. Together, these describe the requirement to retrieve systems that contain motor-like components, and in which a force input leads to a movement as an output action. The results shown on the right-hand side include biological systems, e.g. muscles, protraction of wings, etc., and artificial systems e.g. stator, rotation of rotor, etc. The order of display of results is according to exact match (highest priority), partial match, exact synonym match, or partial synonym match (lowest priority).

3.2 Representation of a System

The systems retrieved are represented in the tool as shown in Fig. 3. The elements of the multi-modal representation used include: a multiple-instance, multiple-system model (top left), individual SAPPhIRE models (top right), audio (middle left), text (middle right), image (bottom left) and video (bottom right). The left and right arrows traverse through the different systems that constitute the multi-instance model; the content represented change according to the current sub-system being shown.

Dependency graph (top left): The multiple-instance, multiple-system model is a dependency graph displayed using JavaScript. It uses a recursive function that takes a system ID as argument and displays all the systems for which the current argument is parent. The systems are then connected using edges, so the the multi-instance, multi-system model can be visualized. The dependency graph is a dynamically changing script that is updated with updates in the database. Systems newly added or linked with existing ones are immediately reflected in the visualization. This feature is not present in any earlier tool. Further, as noted earlier, it supports any level of hierarchy.

The **SAPPhIRE model (top right)** is structured according to the information fetched from the database. The **audio (middle left)** is generated using a text to speech translator that recites the textual information about the various systems and links in the multiple-instance, multiple-system model. However, the audio does not explain any system in detail. The **text (middle right)** that follows a template, gives a detailed explanation of the SAPPhIRE model and an overall explanation of the system currently viewed by the user. The **image (bottom left)** and **video (bottom right)** are open source materials fetched from the internet for providing additional information on the system. This, we argue, should provide a more integrated understanding of the system.

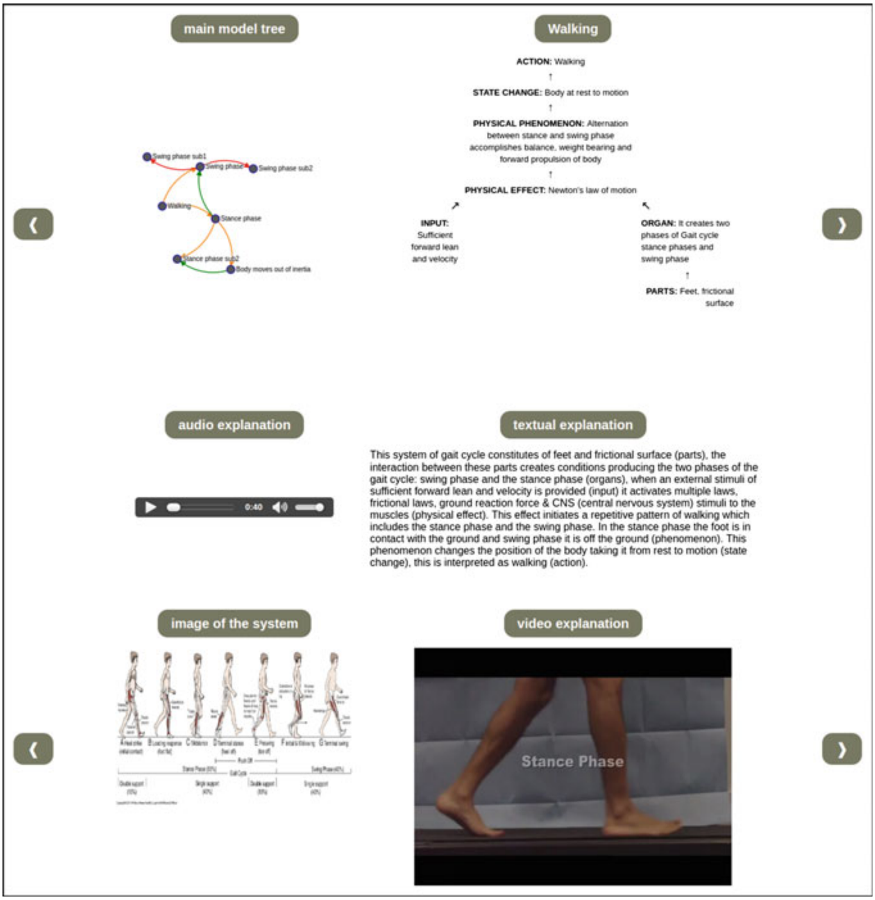

Fig. 3 A multi-modal representation of a system in Idea-Inspire 3.0

3.3 Adding/Linking a System

This feature supports the user to add new systems to, and to link existing systems in, the database; as explained before, this feature was not available in any earlier tools. The feature, however, is available only for authorized users. Using this feature, the user can add new systems, both as SAPPhIRE models and as textual explanations. Each SAPPhIRE instance is stored in the database as a new row for a system, which is retrieved for representing the system. The existing systems are linked through a different page for generating the dependency graph (Sect. 3.2), which shows a combination of existing systems represents a complex system.

4 Summary and Conclusions

The tool that we had intended to develop needed to carry the following features: given a design problem, one can retrieve descriptions of systems from natural and artificial domains that could act as stimuli for ideation to solve the problem; uniquely represent each system for adequate understanding; and support the user add new systems.

The system retrieved using the tool is displayed using a representation that utilizes multi-instance, multi-system model with individual SAPPhIRE instances, text and digital support. The newly introduced multi-instance, multi-system model is a dynamically changing script and supports any level of hierarchy. The representation, which is introduced in this web-based tool, is much advanced than its earlier version. Adding and linking of systems is a unique feature for the tool; the resulting changes could be visualized immediately. Idea Inspire 3.0 has novel features for supporting understanding, ideation, synthesis and expansion of its knowledge base. A preliminary testing of the tool suggested that there is need for user training before utilization of the tool. Further development and more extensive evaluation of the tool are part of the work in immediate future.

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A Matrix Framework Proposal for Evaluating Innovation Criteria of a Design Process Output During Product Conceptualization

Ravi Lingannavar, Sai Prasad Ojha and Pradeep Yammiyavar

Abstract The paper contributes to the existing Design thinking process by integrating the concept of "Design Matrix" into it. Design matrix focuses more on the measurement of innovation. The positive effects of introducing design matrix are validated through the final prototypes of the three design solutions. The first one involves users who are making different envelopes of various sizes. The second case study involves making of paper bags of standard size. The third case study involves the same set of users making office files. The paper attempts to validate the applicability of Design Matrix to three product case studies. At first glance the problems chosen are very simple but when seen from User's point of view and by using a matrix—innovation is attempted to be measured. The authors contend that Innovation need not necessarily mean complex thinking or solving complex problems. The paper concludes with proposing future application of processes Design Matrix for complex products.

Keywords Design matrix · Design thinking · Product design · Innovation · Creativity

1 Introduction

Design is an activity to convert an undesired situation into a desired situation [1]. 'Design Thinking' is a methodology used by designers to solve complex problems, and find desirable solutions for clients. Design Thinking draws upon rationale,

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creative energy, instinct, and systemic thinking, to investigate conceivable outcomes of what could be, and to make fancied results that advantage the end customer. A designer mentality is not problem centric, it is solution centric, and activity oriented. It includes both examination and creativity in equal measures so as to achieve innovation. Portions of the recognized characteristics in Design Thinking are [2]:

- Finding straightforwardness in many-sided quality
- Beauty and in-addition usefulness
- Improving nature of experience
- Creating rich solutions
- Serving the requirements of customers

Design thinking acts as a strategy of innovation. When design principles are applied to strategy and innovation the success rate for innovation outcomes dramatically improves [2]. Design thinking is at the core of effective strategy development and organizational change. Design can be applied to products, services, processes, physical locations everything that needs to be optimized for human interaction. We can design the way we lead, manage, create and innovate. Some of the basic questions that motivated this study were

- How to recognize innovation during product conceptualization by means of design thinking?
- Can there be heuristics of designing innovative products as against simply designing products?
- Can there be a method of quantification of innovation in products?

In this paper Design Thinking process is observed while a set of three simple product designs are being worked upon by three designers. Intention is to isolate those steps in which innovation happens. Design Matrix approach is adopted in the quest to measure incremental innovation as the product's design unfolds and evolves into a prototype.

2 Review of Literature

Innovation has many definitions, Drucker [3] defines innovation as "entrepreneur and entrepreneurship—the entrepreneur always searches for change, responds to it, and exploits it as an opportunity". Robert Bastarache [4] defined Innovation as the summation of Value, creativity and execution. Innovation is the blend of desirability; feasibility and viability. The desirability is the likes of a user, feasibility is what can be achieved with the technology and viability is the ability of the design to be realizable.

Innovation can be of various types [5] like product innovation, process innovation, organizational innovation, management innovation, production innovation, commercial/marketing innovation, service innovation etc. Cropley and Cropley [6] provide a useful definition for creativity and innovation of engineering products in which creativity is a four-dimensional, hierarchical model that must exhibit relevance and effectiveness, novelty, elegance, and 'generalizability'. Figure 1 shows the path in which the innovation is obtained if design thinking is implemented according to Naiman [2].

Innovation is often widely used as a hype term in management and business [7]. However, its essence is felt only while practicing it. Learning and teaching innovation is increasingly confined to knowing about it rather than knowing how to practice it. Naiman [7] has mentioned in her frame work for creativity and innovation (in Fig. 2), about the iterative process of product design indicating the complex processes. The framework gives different steps which a designer need to think to finalize the idea.

There are several methods mentioned in literature to access innovation and creativity in the designing processes. Muller et al. [8] compared two different design innovation process model for design thinking. Some of the commonly used evaluation processes include the Weighted Objectives Method [9–14], Pugh's Method [15], or the Datum Method [16, 13, 15, 17]. There are many other methods reported in literature which help designers. Methods such as Robust Decision Making [16] provide designers with a detailed account of what decision making entails, how to make robust decisions within team settings, and how to best evaluate alternatives. Many engineering design textbooks, such as Otto and Wood's Product Design [18], Ullman's The Mechanical Design Process [16], Paul and Beitz's Engineering Design [9], and Ulrich and Eppinger's Product Design and Development [17], provide an overview of how to make design decisions when faced with numerous alternatives, they are very effective, but do not necessarily focus on creativity and innovation as integral design requirements.

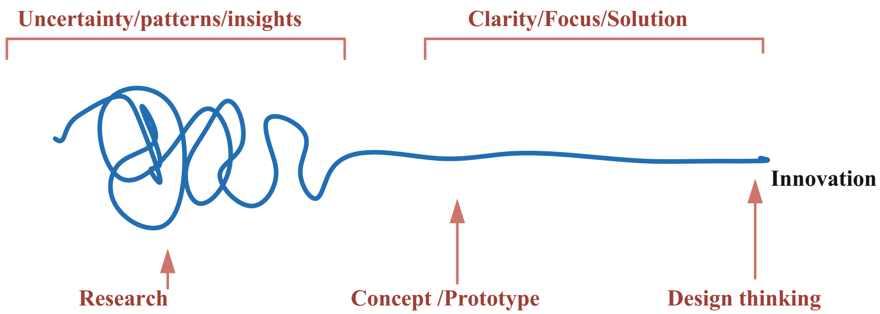


Fig. 1 Path to innovation [2]

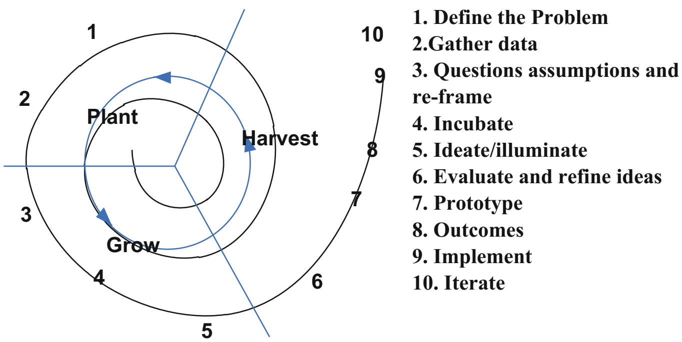


Fig. 2 Framework for creativity and innovation [7]

All the above are more of gross designing methods rather than innovation indexing tools. There seems to be a dearth of such tools. When simple products are under conceptualization and no complex solution is required due to less number of variables—the recognition, of innovation, at what stage it happens and if so what is the incremental value that gets added—are difficult to isolate. In simple product designing in which very few physical parts are involved or in which the hands themselves are the main tools (for example folding paper to result in an envelope, innovation even if happening, may not be noticeable or identifiable or even for that matter measurable).

One possible approach could be to perform a task analysis as the designing process unfolds. When tasks are broken down—each one can be mapped to incremental addition of value. It is expected that such values summation could be a metric for innovation.

To focus on the integral design matrix, we need to choose the elements of design matrix. The next section briefly describes the elements used in the Design Matrix, which are ultimately used to measure the innovation potential. This in turn will help us to compare the designs which can range from simple to complex products.

There are several cited research works on measuring creativity on a scale such as CPSS, CAT, SPAF, Moss metrics, Sarkar and Chakraborty, etc. [19, 20, 21–23]. Models like Kano, Design structure matrix, QFD etc. will guide us to understand and quantify need, problem complexity, satisfaction and solution for the customers. In addition, metrics like ROI (return on investment of a novel idea) will give the profits on the investment which can become an indirect value measure for innovation. This will lead us to estimating innovation potential of the product as well as firm especially during its conceptualization and development cycle. This factor could be a boon to industry with limited resources such as small scale industry or artisan enterprise in India.

3 Adoption of Proposed Metrics

From the literature studied two broad factors have been identified in this paper that could assist measurement of innovation. They are (i) Novelty (ii) User Centered specifications that become criteria for design evaluation.

Novelty in a product is an indicator of embedded innovation. As reported by Justel et al. [24], the newness of an idea (novelty) can be evaluated by taking a degree of novelty as level of curiosity and its Patentability. The degree of newness, a measure of innovation has many dimensions, as reported in literature. Any product having more number of dimension leads to high score and high degree of newness. That leads to the higher degree of innovation prospect. A work carried out by Gracia and Calantone [25] is referred to for constructing Table 1 to obtain degree of newness. Apart from this, designers can contribute in assigning the degree of newness, based on their experience and knowledge of product context based on the listed discontinuities (Table 1).

User centered Design criteria resulting from user centered need are central in the Kano model. These factors are measurable and hence are being opted in this paper as possible metrics for innovation.

Design criteria are recognized and fixed in view of the customer's needs, feedback as carried in Kano's survey [26]. It is observed that in general for any product to be successful, customer need is to be considered in designing phase. If the customer feels his requirements are fulfilled then automatically he is satisfied, which will lead to the success of the product. Equation (1) below is used for the estimation of Sheer Innovation Prospect which is adopted from the Ref. [24]

$$\text{Sheer Innovation Prospect} = \left\{ \begin{array}{l} \sum_{i}^{n} \text{Particulars} - \text{Concept Relationship} \\ \times \text{Criterion Weights} \end{array} \right\} \times \text{Degree of Newness} \tag{1}$$

Table 1 Dimensions of newness in products (discontinuities [25])

Relationship of the product	Dimensions of newness
New to	World, industry, science and technology community market, firm, customer
New in what?	Technology, process, product features, product design, product line/assembly line, service, competition, customers need, usage pattern, development skills, marketing/sales/distribution skills, knowledge base, quality etc.

Table 2 Showing the frame work after modifying the one suggested by Justel et al. [24]

			Conceptual designs	**Design 1**	**Design 2**	**Design 3**
			Degree of newness 2			
Sl no	Design methods	Design criteria	Criterion weightage			
1	Brainstorming	Low Cost	1	3		
2	Lean thinking	Light Weight				
3	SCAMPER				4	
4	Group discussion					
			Absolute Innovation prospect			
			Normalized Innovation Potential		5	
			Rank			

1. Selection of design criteria based on cost, weight, time etc. as shown in Table 3

2. Assessment of the degree of newness of conceptual designs the designers identify newness based on Table 2
3. Evaluation of the sheer innovation prospect of all designs
   Design criteria are placed in 2nd column, and criteria weights are given according to their significance
4. The correlation between design criteria and conceptual designs is determined in the matrix. With this we can evaluate that how well each conceptual design meets for a given design criterion. (Design Criteria strong = 9; medium = 3; weak = 1)
5. The Sheer Innovation Prospect of all designs is calculated by using Eq. 1. It is then normalized to attributing a value of 100 to the highest-scoring design and corresponding scores are calculated for all designs
6. The final scores then are multiplied by from Eq. (1) Degree of newness which will be the final scores of all design and highest scorer will be more innovative than other designs. Frame work for the identified problems with weights and ranks are shown in Table 3

4 Experiments

The proposed metric concepts discussed in this paper were subjected to trail via three design cases involving development of simple products for use by mentally challenged users. Developing products for differently abled people is a user centered design criteria based challenging task. Ease of operating by the challenged, along with the novelty of the solution was under trail in the cases taken up for evaluating the innovation component of the design and also to find out if a matrix approach to design evaluation can be evolved. The experiment task was to construct an evaluation matrix, evaluate by ranking—the three products and the methodology undertaken by the three designers. The three case studies were observed while the designers were in the process of designing, prototyping and improving the designs.

These three devices were meant to facilitate self-employment of the mentally challenged users so as to encourage them to lead an independent life. Products to be produced by them using the devices under design by three designers—were (i) Handmade envelopes, (ii) Paper bags and (iii) Office files.

Before embarking on the design of devices field studies done by the designers of the devices—involved 8 user subjects and their supervisors. Observation and photo documentation suggest that the mentally challenged user subjects who were involved in making these envelopes were taking excess time and performed more number of steps to make an item. Another difficulty that was faced by them was inability to maintain dimensional standards and consistency resulting in large variations in quality and finish. Constant prodding to try and adhere to proper dimensions was contraindicated for the user subjects. The user subjects employed traditional paper cutting methods using sharp knives and blades which could not be allowed unsupervised. Since they are differently abled the chances of getting hurt was always there. The folding, gluing and packaging of these envelopes done by the user subjects were not perfect. There was a need of design and innovation intervention in this problem. Similarly, other products made by them such as paper bags, office files, also needed design intervention and improvement.

Three designers engaged themselves in creating interventions for three products namely (i) envelopes (case 1), (ii) shopping bags (case 2) and (iii) office file folders (case 3). Designers used different design methods such as brain storming [27], SCAMPER, Lean Design thinking [28], and other methods to resolve the problem. The task for the authors of this paper was to evaluate the end resulting devices and rate their designs on innovation criteria. To select the most innovative and effective design amongst the proposed designs involve devaluating a series of interconnected outputs. A design matrix frame work was developed on similar grounds to that proposed by Justel et al. [24]. It was modified according to our problem and adopted.

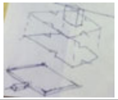
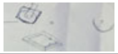
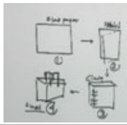
Designs of the three cases were subjected to evaluation using the proposed matrix frame work by the authors and is shown in series of Table 3.

The collaborative design process is shown in Fig. 3.

The designers followed different methods to solve the problem. Designer 1 used brain storming method, designer 2 and 3 had used SCAMPER to generate the concept and then followed the process as shown in Table 3. The collaborative design followed the lean design thinking and group discussions to generate the solutions. The different innovation potential was calculated as shown in Table 3. It was observed that from all designs the collaborative design was having a higher Innovation potential and was ranked higher than others. It was chosen for the final solution. Since the requirement of the given problems was limited hence the size of the sample is less. The sample size and complexity of products will be increased in further research work.

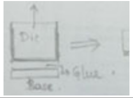
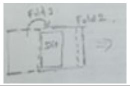
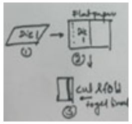
Inferences: From all designs the collaborative design outcome was ranked higher and rated with higher Innovation potential. It was chosen for the final solution. The final Designs for the three cases are shown in Fig. 4.

Table 3 Comparison of different designs with design criteria and innovation prospect

		Design methods applied	Degree of newness		Design criteria (strong = 9; medium = 3; weak = 1)								Sheer innovation prospect	Rank
				Criterion weightage	9	9	9	9	3	9	3	3		
Problem 1: paper envelopes for differently abled people					Low cost	Light weight	Efficiency	Functionality	Good ergonomics	Ease of use	Maintenance	Less process time		
Case 1														
Design1		Brain storming	1		3	1	1	1	1	3	3	9	120 * 1	4
Design 2		SCAMPER	1		3	3	3	3	1	3	3	3	156 * 1	3
Design 3		SCAMPER	3		3	3	3	3	3	3	3	3	486 * 3	2
Collaborative		Lean design thinking	3		3	9	9	9	3	3	1	3	954 * 3	1
Problem 2: paper bag for differently abled people				Criterion weightage	9	9	9	9	3	9	3	3		
Case 2														
Design 1		Brain storming	1		3	3	1	1	3	1	1	3	102 * 1	3

(continued)

Table 3 (continued)

		Design methods applied	Degree of newness		Design criteria (strong = 9; medium = 3; weak = 1)								Sheer innovation prospect	Rank
Design 2		Concept Screening	1		3	3	3	1	3	3	1	3	237 * 1	2
Collaborative		Lean design Thinking	3		9	3	9	3	3	9	3	9	342 * 3	1
Problem: office file for differently abled people				Criterion weightage	9	3	9	9	3	9	3	3		
Case 3														
Design 1		Concept screening	1		3	3	1	1	3	3	3	1	102 * 1	3
Design 2		Brain storming	3		3	3	3	3	3	3	1	3	138 * 3	2
Collaborative		Lean design thinking	3		9	3	9	3	3	9	3	9	324 * 3	1

Die:1- Cutting → Die:2-Folding → Envelope

Fig. 3 Collaborative design process

Fig. 4 Final solution for three cases (**a** envelope, **b** paper bag, **c** office file)

5 Conclusions

Conceptualization of design based on creative ideas and selection of ideas is very important in the product design phase. Currently absence of well-defined techniques for selecting product concepts based on innovation criteria has lead us propose a Design matrix based metrics with which we can assess the 'innovation prospect'. Design Matrix approach is adopted in the quest to measure incremental innovation as the product's design unfolds and evolves into a prototype. Future development of the matrix for a complex product is proposed. Such a matrix is expected to have many sub matrices with complex interrelationships between them. Individual matrices for materials, processes, usability etc. of the product have the potential in enhancing innovation through design thinking.

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Design Fixation and Creativity Blocks in Architecture Design Studies

Purva Mange and Vinayak Adane

Abstract The process of designing includes, generation of the creative and innovative concept as a major step to give design projects a direction. The design is majorly defined as a problem-solving exercise of cognitive (internal) and interactive (external) thinking. In this process due to an odd combination of internal and external inputs, a number of hurdles and stagnant situations appear which consume a lot of creative time. These pauses, moments or breaks are termed as blocks and fixations based on their characteristics. The paper elaborates on the identified blocks and fixations in the architecture studio design process in context to the student's experience. The fixation or the blocks are specific to Students domain which varies according to the content and Pedagogical approach. Hence the typology of fixation is kept constant and mapped according to the three years of architecture and in three zones for different pedagogical approach. Thus the interesting patterns obtained are inferred.

Keywords Creativity · Cognition · Design fixation · Mental blocks · Visualization

1 Introduction

In architecture education, design is a sequential process and design learning is an experience [1]. Moreover, the project typology generally directs the parameters of the learning process. However, the problems in the design process do not get identified as the focus is on output, marks, timely submission, etc. The problems in the design process have their roots in 3 areas, the Individual, the Process/pedagogy and the Content (external/global/market/vernacular) [2] have similar stand point on the same. Presently a lot of standardized techniques are used in design institutes

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often without a thought of its application and adaptability for the present and future architectural scenario. The traditional approach that follows the principals and practices developed in the past which are not equipped to deal with the practical reality of contemporary societies to a more responsive approach that effectively challenges recent sciences, construction techniques, and telecommunication technologies is discussed in detail in the book named Design Studio Pedagogy: Horizons for the Future.

Generally, design thinking starts on an individual level mainly based on cognitive skills. The student's individuality is a strong influential factor to take design decision based on cognition. Cognition skills have limitations if not decoded in an explorative way. These situations result into the serious issue which is identified as Design Fixation and Creativity Blocks. Most of the Design Fixation are due to unawareness and lack of understanding of the situations hence is left unaddressed. Survey of the literature on design pedagogy [1, 3] reveals on the other common reasons for design fixation as- (a) lack of knowledge and or data, (b) lack of experience, expertise, and skills, (c) lack of decision making skill, (d) reflection of cognition, (e) lack of interest, (f) low aims, (g) improper collaborative design (strong thinking/dictation of teacher/students inflexibleness for exploration), (h) amateur understanding, (i) Handling a design typology of project for the first time, (j) lack of imagination in 3rd dimension and reluctance to explore through alternative means [models], etc. The existence of design fixation is supported by the experimental research [4].

Architectural design pedagogy is a routine process with little improvement or change over the past few decades. It is observed that framing the pedagogy should be tailor made according to the requirement of a particular batch and thus in-depth understanding is required for the same [5]. However, the current education system appears to be rigid as many institutes as well as faculty members are not very keen for such radical changes. Nisha Fernando [6] finds fault in the traditional teaching methods, which cultivate the dichotomy between knowledge and creativity in design, while taking up old dilemmas and new strategies in design studio is elaborated.

Moreover, the 'external world' factor also has a major impact on design fixation. The architectural design has become an assembly of the accepted products and services contributed and governed by the external factors. One product or service dictates other, and the chain continues. The exploration at the initial level of ideation does not happen, and the acceptance for the market trends is high. Hence, the output is standardized which also result into a serious issue of Design Fixation and Creativity Blocks. Thus after the study of existence of these serious issues of fixation with their typology it is important to understand the pattern and factors in the typology of fixation which is beyond the scope of this paper.

The aim of the study is to understand the fixations or block to creativity created in an adopted design process based on architecture student's opinion.

1.1 Creativity Blockages and Design Fixations

A sizable amount of work has gone into an understanding of design fixation in a process of designing and for the individual. Further, the methods are investigated with cognitive models and prototyping, etc. and the fixations on the no of ideas produces [7] categorized design fixation as- (1) **Unconscious Adherence**: Cognition is reflected as a new and novel idea. (2) **Conscious Blocking**: Designer intends consciously to accept the borders and unable to break them. (3) **Intentional Resistance:** Designers are self-obsessed with the designs they are working on.

The C-K design theory (i.e. knowledge cognition theory) stated the model of fixation, where a creative reasoning to the task is evaluated based on cognition and knowledge. C-K design theory or concept-knowledge theory is stated as a design theory and a theory of reasoning in design. The fixations are also characterized as restrictive heuristics. Agogue et al. [8] experimented the C-K theory models for creative learning at knowledge space and concept space.

In general the fixations are due to data, new strategies, functional complexities, Cognitive fixations, etc. There are mainly two types of pause nodes which are termed **as mental blocks and design fixation**. Getting stuck due to lack of experience and expertise is termed as ***Metal Blocks.*** The mental block is the ones which occur due to lack of visualization for the end result. The student gets stuck and needs inputs to find an alternative or drops the idea and moves ahead. They are randomly spread through the process [3]. Whereas ***Design Fixation*** is designing in a limited domain due to obsession, passion, fashion, etc. Fixation refers to a block formed by impediment things to reach the end, at sometimes even not being able to visualize the end. Design fixation occurs more at a stage in the whole design process where divergent thinking is required. The students are not able to create multiple options and keep pondering with the same ones with minor alterations. Hence unable to find the direction and make a decision. It is stopping memory operation, problem-solving and creative ideation [8–11].

Understanding fixation is critical as they are emotional, physiological, material based, personal to the project specific, etc. The fixations under the design studies have been identified. Formation of fixation is unconscious, and they need the conscious ways to solve it. The fixations also differ from Novas' to experience holders. Design fixation brings a very negative impact on design process [13]. They suggest the use of external stimulas of Analogy to overcome these fixation.

1.2 Methodology

The study sample is spread across the three zones of India form first, second and third year of Architecture colleges. The study is based on the opinion of Architecture students on 4 point scale for the design fixation and mental block faced in design studies. The sequential method has been explored to achieve the deeper understanding in the following:

3.1 Mapping of the design process to identify the pause nodes.
3.2 Ranking the Mental Blocks and Design Fixation as per the level of complexitied at various stages of design.

The experiment is mapped to understand the pondering points and pause nodes with 700 students in 3 zones/University of the country (INDIA) where a diverse approach to teaching and syllabus is followed under uniform directives of the Council of Architecture.

2 Experiment and Interpretation-

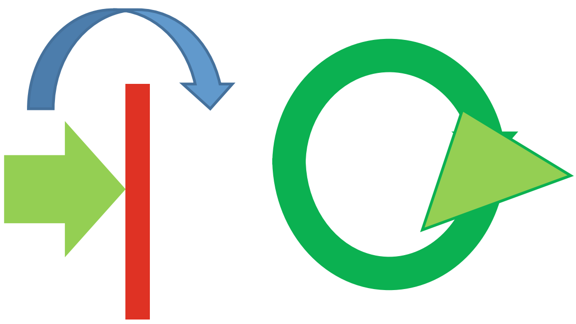
2.1 Mapping of the Design Process to Identify the Pause Nodes

The design process is split in numerous stages and based on the pilot study the most difficult levels were identified. These nodes are concept generation, Divergent thinking/option making, Decision making, Sheet making. In the detailed study the sample also give their opinion on the identified nodes.

Interpretation

In a design process the combination of data (input/generation), Divergent thinking and decision makes together contribute to a design output. All the 3 have a varying role at the different stages in design process. The above Fig. 1 schematically indicates the varying importance of the three factors through their size at various stages of design process. The Divergent thinking that is prominent at the concept generation stage eventually reduced at the end of the process and the decision making factor gradually increases at the tail end of the process. The data input form faculty remains constant at all the identified stages (Fig. 2).

Fig. 1 (*Left*) Mental/Creativity Blocks; (*Right*) Design Fixation



2.2 Ranking the Mental Blocks and Design Fixation as Per the Level of Complexitied at Various Stages of Design

The complete design process was studied for mapping for 4 parameters as identified in Fig. 3. i.e. **Concept generation**, **Options making**, **Decision making** and **Sheet-making**.

Data interpretations

The fixation individually is surveyed, identified, analyzed and plotted as below giving the comparative understanding of classes from 1st year to 3rd year, and 3 zones of country. The three years or zones are represents by three bars in the following graph. The 4 pointer scale is used where 1 is most difficult to 4 as lease difficult. The survey inclusions ranged from ideation stage to presentation i.e., Concept generation (Ideation), Option making (Divergent thinking), and Decision making (Analytical thinking), Sheet making (Penning down the idea and presentation).

The survey was undertaken on over 700 students of architecture from three zones of the country to assess the variation in the experience on mental block and design fixation—almost 68% students accepted the existence of strong mental blocks; where as 16% of them agreed existence of block; 14% disagreed and surprisingly only 2% of the student strongly disagreed. Even the survey of teacher's teaching design supports the existence of mental blocks and design fixation in the design process. Survey for Mapping of the observations in a design studio and mapping of observations of the specially designed short tasks also support the existence of the mental blocks and design fixation.

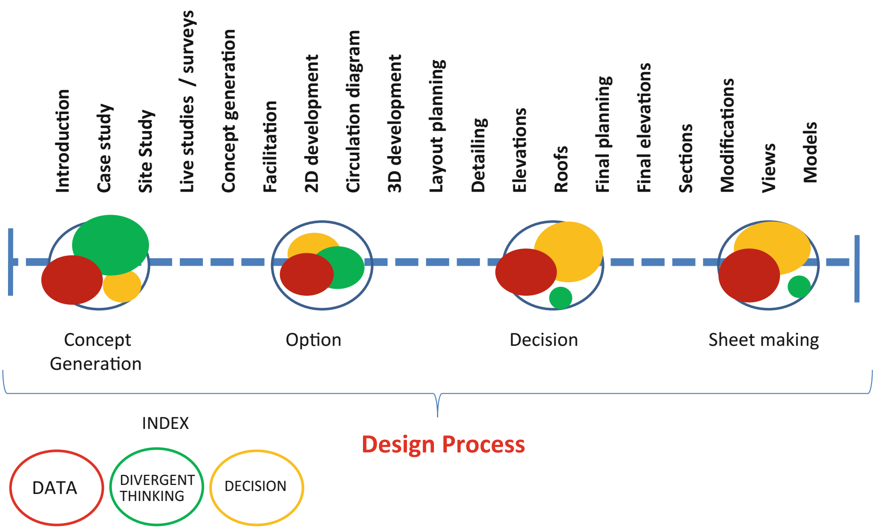


Fig. 2 Mapping the importance of 3 parameters on the 4 stages of design process

The extensive survey undertaken resulted in the following observations-

I Concept Generation—The ideation stage is stated as the most difficult by students from all years and zones of the country.

II Options making—The most crucial stage in design is where divergent thinking is most important. Understanding and implementing helps make decision faster and develops analytical thinking. The students from 2nd and 3rd year tend to

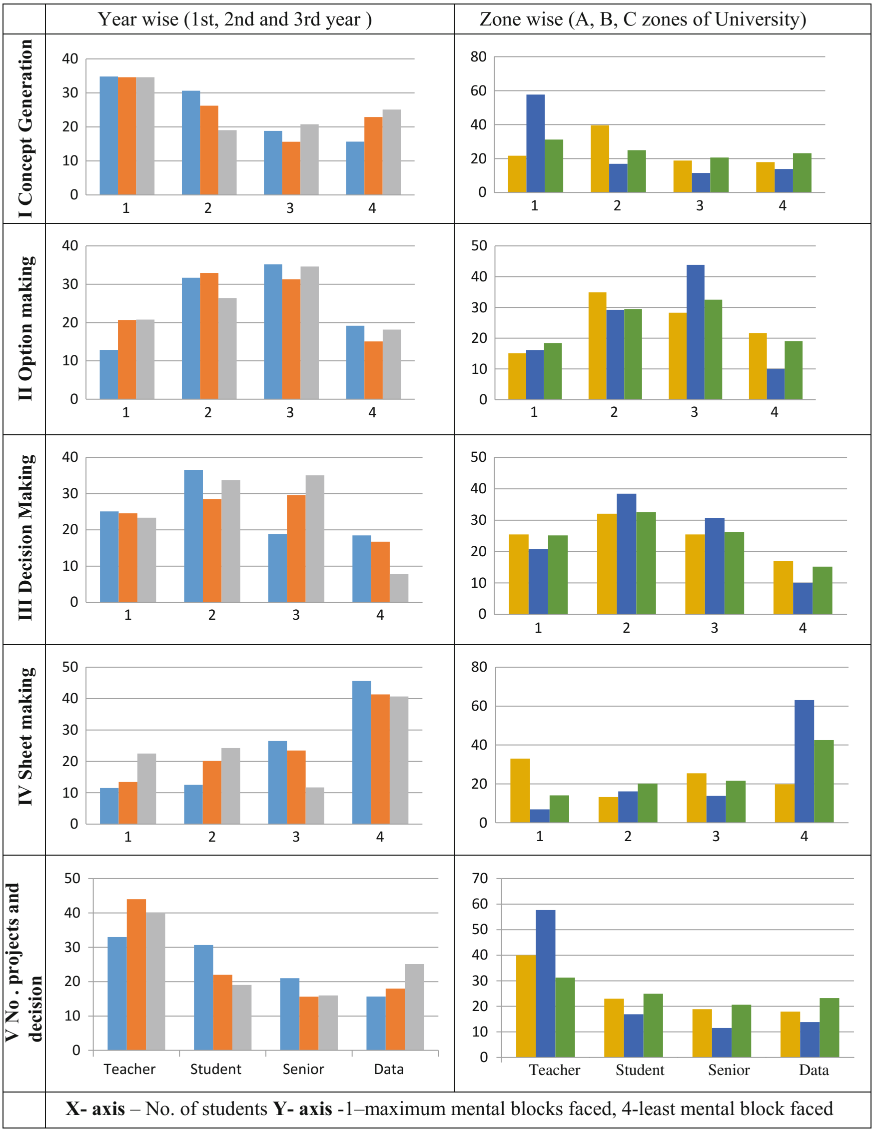


Fig. 3 Student's response to various tasks in design process

rate the option making or divergent thinking as a crucial fixation point irrespective of the university.

III and V Decision making—is a frequently reoccurring phenomenon in the process of designing and unaware of this fact student rank this at level III, the controversy is supported at the 5^{th} stage where students confess that their reliability is more on teachers to select the options than their personal choice or opinion or based on data base analysis.

IV Sheet making—basically penning down the things. Once the data is derived sheet making is easier and hence student ranked it at 4th place.

The above data indicates the students inclination to face a mental block at concept generation stage is higher than to option making, decision making and sheet making. Thus the design fixation issue become seriously serious at an ideation stage

3 Conclusion

The paper methodically describes the serious issues of fixation in the process of designing. The pause nodes appear due to the pedagogical methods adapted which in themselves are restrictive and limiting. The paper talks about the existence of pause nodes whereas the factors responsible for their emergence are unanswered in this short compilation. The fixations are not restricted only to the starting point of concept generation but are distributed through the design process and the majority of them are due to lack of proper analysis of data to take decisions.

Thus the results obtained from the 3 zones of the country unanimously support the existence of fixations. The mapping of the results for the process of Designing highlights 2 major nodes i.e. **decision making** for mental blocks and **divergent thinking** for design fixation (i.e. less of variation in divergent thinking).

As the project complexity increase with the higher years the pause nodes multiplies. The students mainly depend on their teachers to take the design decision for them in studio design projects (Fig. 5-V) instead of data analysis and surveys.

The process of Designing should not be restricted to introduction and solution of a design project, but much more beyond at final stage of completion i.e. framing the problem and analyzing end result. Proper data inputs in the whole process, may help to reduce the emergence of mental blocks.

Further research should investigate the detailed pattern of emergence of these pause nodes (thinking) in and out of design process. Identification and designing stimuli to overcome these pause nodes is yet another challenge. Thus, decades of accumulated practices will be supported or discarded the new research parameters with the new enraging trends in pedagogy. Experimentations on the same will help map student's response. All this research when carried out with students from a particular domain will help understand the fixation domains in detail and depth.

Thus, a seriously serious thought on these paused nodes shall help to enrich the design teaching and design learning process and enhance creativity.

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A Framework for Component Selection Based on Multi-attribute Evaluations

Stueti Gupta

Abstract In complex products, the selection of a component is often not done in isolation, but as a part of the decision of selecting the right combination of components for the product. Thus, the criteria for selection include performance requirements and other attributes of the complete product system as well. In this paper, a framework is presented wherein a single master model is used to capture the information about all combinatorial design options and parameters for individual component choices. The requirements for the product, attributes of interest, as well as context related assumptions or constraints are also captured in the master model. The Systems Modeling Language (SysML) is used to define this master model. An example case study of component selection and trade-off analysis to determine the optimal selection of a wiper system is presented to demonstrate the use of the suggested framework.

Keywords Systems modeling language (SysML) · Component selection · Model based systems engineering · Design exploration

1 Introduction

A complex product development involves design and selection of several components that make up the product. It also involves several domain experts who use their domain specific tools to perform various analyses. Several combinations of the components are available to assemble the product. Individual component choices cannot be made in isolation but traditionally the criteria for selection of components are based on evaluation in independent domain specific tools. Evaluation of such attributes employs different methods and requires different details about the component and the parent product or system. Models are often created in different tools to evaluate specific attributes. However, such an approach may be susceptible to

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errors due to inconsistencies in the models and different assumptions used for different evaluations. Moreover, additional steps are needed to further collate the results from different models in order to perform the trade-off analysis and choose the right combination of components.

Poor decisions during early phase of design lead to extended project schedule and add cost to the project as changes are difficult to make later in the product development cycle. Design catalogues for material selection and standard parts such as bearings, o-rings, etc. are used by designers. Exploring the design space having several options of components and evaluating their combinations against system attributes helps mitigate the risks of schedule delays and added cost. Commercially available options, such as iSIGHT™ [1] and modeFrontier® [2], are popularly used as multi-objective and multi-disciplinary optimization software which integrate with third party design tools to explore the design space. However this approach requires configurations to be setup as well as has the need to have a specialized tool to enable this analysis. Researchers at MIT developed a framework for tradespace exploration called MATE (Multi-Attribute Tradespace Exploration) [3] towards the development of space systems which does not recommend any specific software tools or formula. Using Systems Modeling Language (SysML) and General Algebraic Modeling System (GAMS) [4] component sizing problem is researched to evaluate multiple scenarios for a given configuration. This method requires model transformation and specialized GAMS stereotyped blocks in SysML.

Due to increasing complexity of products the design task of selecting components or sub-systems, is becoming more and more a decision that needs to be taken keeping system level performance/attributes in focus, rather than component specifications. Model Based Systems Engineering (MBSE) provides a formal framework to model the complexity in the system in terms of requirements, structure, and behavior, including parametric inter-dependencies. MBSE is an evolving approach that lets you consider system level attributes. In this paper a framework for component selection is presented to perform multi-attribute evaluations using SysML applying MBSE approach. SysML is used to create a master model of the products and their components which includes information such as system requirements, system structure and behaviour. A mathematical solver and parametric models defined in domain specific tools are internally used to perform specific attribute calculations, while providing the input information from the master model. This ensures that the input information used is consistent across the evaluations.

2 Master Model Development Using SysML

SysML is a general purpose graphical modeling language with a semantic foundation for system requirements, behaviour, structure and parametrics and can be further integrated with other engineering analysis models. It is a subset of UML 2 with extensions and leverages the OMG XML Metadata Interchange (XMI®) to exchange modeling data between tools, and is intended to be compatible with the evolving ISO 10303-233 systems engineering data interchange standard.

SysML supports the specification, analysis, design, verification and validation of a broad range of complex systems via various diagram types as seen in Fig. 1. SysML's graphical constructs enable defining hierarchy, internal connections of a system and constraints on system properties, system behaviour such as functionality, data/control flow sequence, state transitions and activity and the system requirements.

The system hierarchy and information on system architecture, at a logical or physical level, can be represented using the SysML block definition diagram (BDD). The BDD also has the capability to describe quantitative values and relationship within or between systems and sub-systems. Connectors are used to define the relationships where every connector has a specific meaning.

A vehicle wiper system is used as a case study for the purpose of this paper. A BDD is used to represent the context of wiper system. The context describes the entities that interact with or influence the system operation and in this case consists of the wiper system itself along with the user who will operate the wiper, the windshield over which the wiper will operate and the external conditions under which the wiper will be operated as shown in Fig. 2. The connector used between the block "Wiper_System" and the block "Wiper" states that there exists a 'part-of' relationship between the two blocks. The connector used between the block "ExternalConditions" and the blocks "Rain", "Dust" and "Snow" states that there exists a 'type-of' relationship between them. Other considerations in a context such as government regulations, customer, etc. are kept out of scope in this study. Properties of entities in the context form essential inputs to physics modeling and analysis of the system.

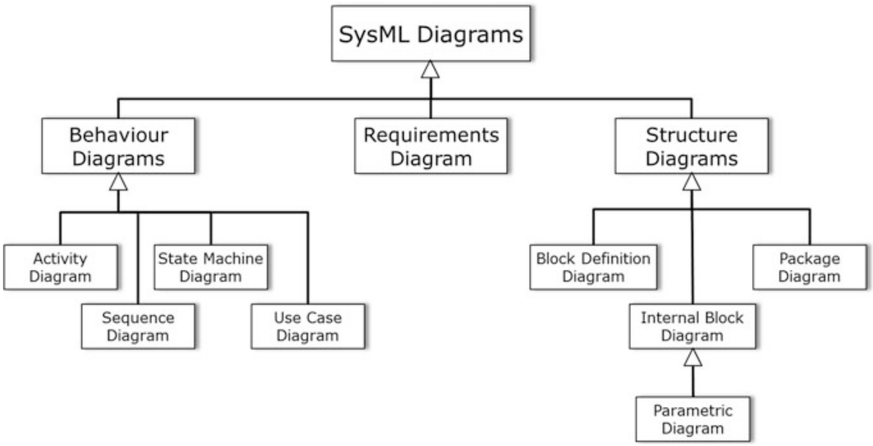

Fig. 1 SysML diagram taxonomy [5]

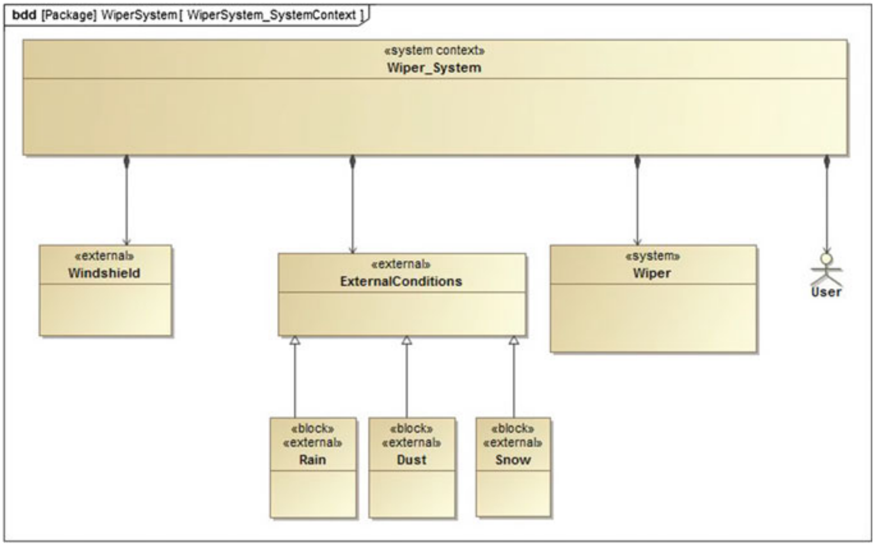

Fig. 2 Wiper system context using SysML block definition diagram

Figure 3 describes the hierarchy in wiper system for the given context. The components are defined as blocks thus the wiper system under study consists of two main sub-assemblies, the motor assembly and the linkage assembly.

In SysML using 'type-of' relationship possible variants of a block can be defined. In this case, three options of motor are being considered and are represented with the 'type-of' relationship as shown in Fig. 4. Similarly there can be variants described for controller and sensor as well as for various parts in the linkage assembly.

Each block in the wiper system hierarchy has parameters also known as value properties that define the characteristics of the block. For example, each block has a characteristic *Price* to specify the price of the component. Other characteristics such as *Voltage* and *Current* rating of the motor block, *initial_position* and *max_position* of linkage assembly, etc. are defined along with their respective units. Mathematical constraint equations are defined to evaluate system attributes of interest. In this case study there is an interest to understand multiple attributes, such as overall price and performance of the wiper system, for every combination of the components. Number of cycles completed by the wiper in given unit time and the power consumed by the operation in that given time, under different "ExternalConditions", are the performance attributes of interest. The relationship between the parameter *Price* of the motor assembly and the parameters *Price* of the assembly components are captured using a parametric diagram as shown in Fig. 5.

SysML is a graphical representation language and the diagrams created as described in the previous sections form a generic definition of the system. One or many instances can be created with specific information of the system and its

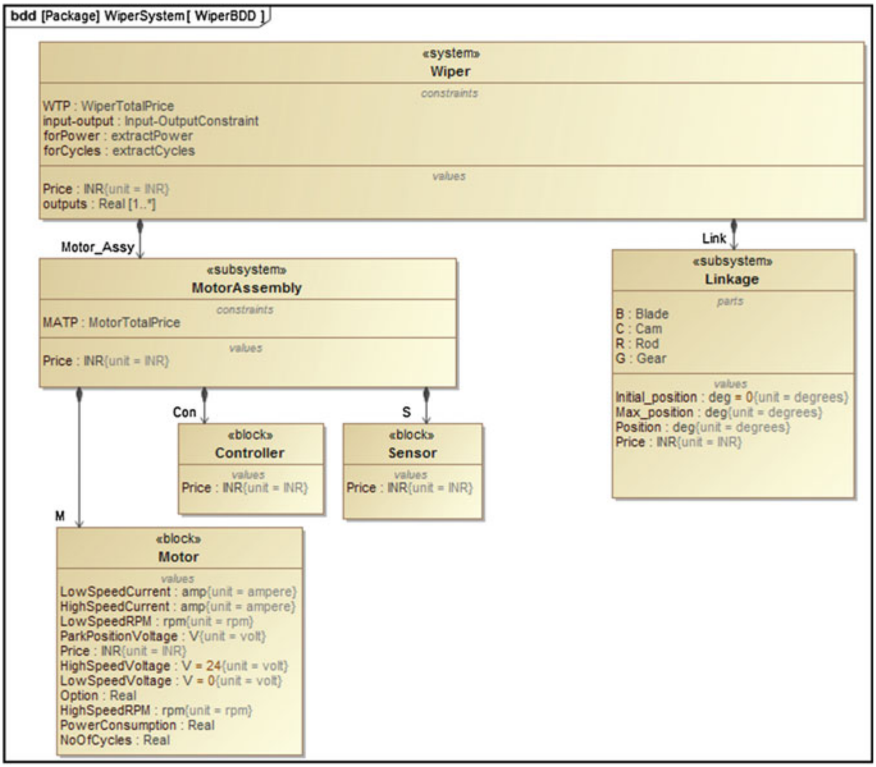

Fig. 3 Hierarchy of components in wiper system using SysML block definition diagram

assembly elements. To enable evaluation of parameters for specific instances it requires a mathematical solver.

SysML models created in MagicDraw and SysML plugin, use solvers such as MATLAB/OpenModelica, and a plugin to interface between the two. Some attributes need domain specific models for evaluation. SysML can be used as a master model to provide that input information. The plugin converts the SysML model to a format readable by the solver. In this case a Simulink® model is needed to estimate the power consumption for a wiper cycle. We create a parameter and a parametric diagram that specifies that relation between the *PowerConsumption* parameter, parameters of components.

The behaviour model of wiper system is created in Simulink® and thereby performance attributes of interest are evaluated by leveraging the existing behaviour model. A specialized syntax [6] is used to provide inputs from SysML environment to MATLAB® solver and get the output values after solving. The cost is a simpler constraint equation summing up the cost of various components in each sub-assembly and is evaluated using the default solver which is OpenModelica.

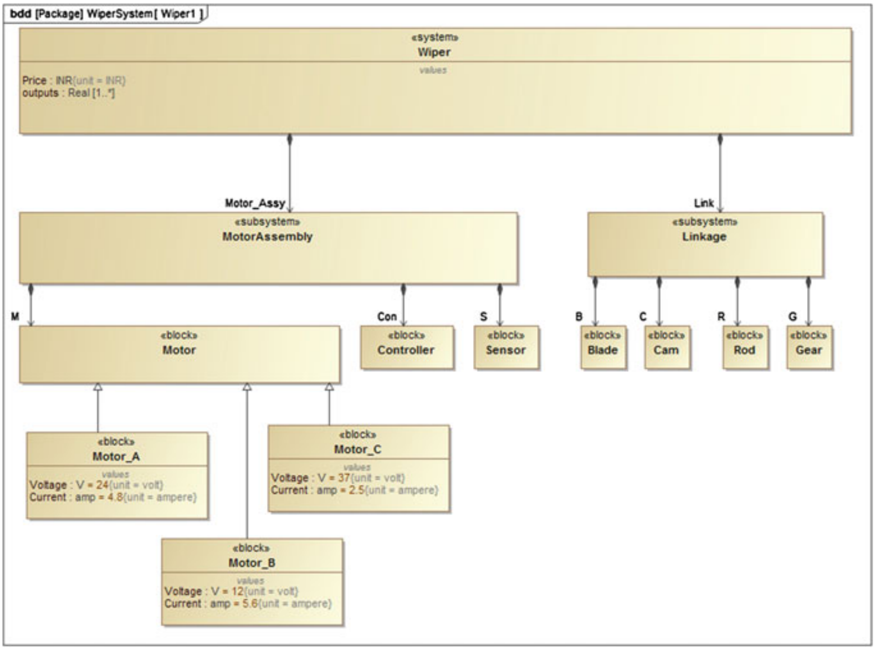

Fig. 4 Showing variants of motors in motor assembly

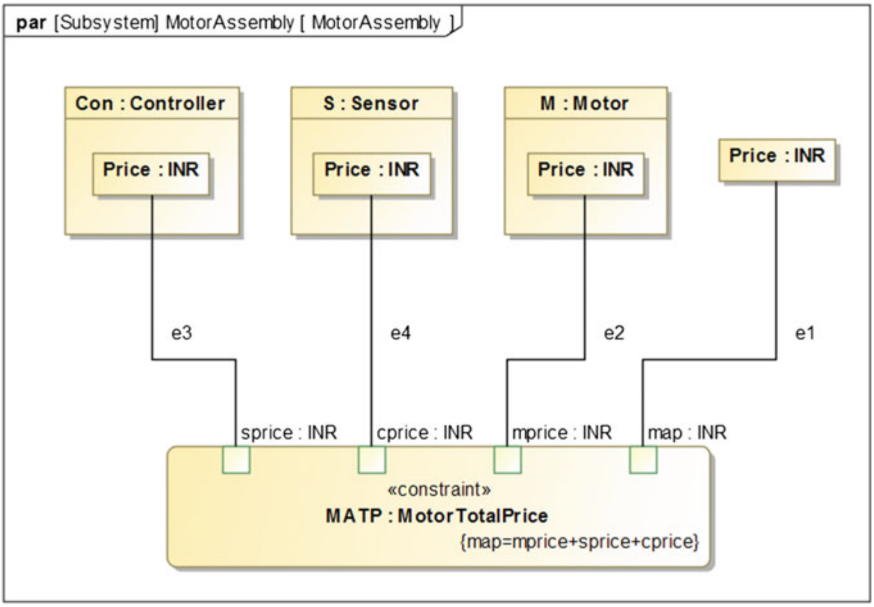

Fig. 5 Parametric diagram relating price of components in wiper motor assembly

3 Results and Conclusion

Figure 6 shows a format of the output screen. As seen in the screenshot, there are three target values, of which *Price* is an output from OpenModelica and *NoOfCycles* and *PowerConsumption* are outputs from Simulink®. Table 1 and Fig. 7 summarize the results and demonstrate the component options in the design space. The results suggest that if Motor 1 is employed then the total *Price* of the wiper system will be INR 17,340 with *PowerConsumption* of 384 Watts and 4, 2 and 1 *NoOfCycles* under the "ExternalConditions" of "Rain", "Dust" and "Snow" respectively. As per the results Motor 1 option is the most expensive option however a designer can refer wiper system requirements to make a decision if the results from performance analysis are more important than the *Price* and accordingly choose the Motor. The SysML model developed is a formal representation of the system.

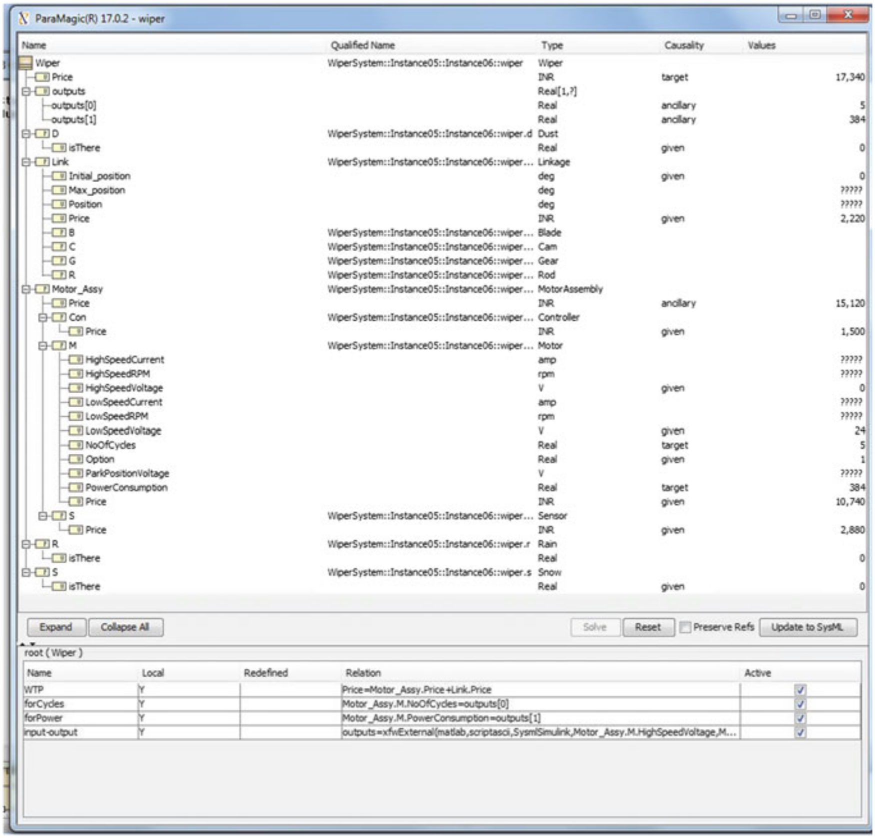

Fig. 6 Paramagic® solver user interface

Table 1 Results of multi-attribute analysis

Motor assembly	Price (INR)	Power consumption (W)	Number of cycles		
			Rain	Dust	Snow
Motor 1	17,340	384	4	2	1
Motor 2	11,400	360	4	2	1
Motor 3	13,170	288	7	5	4

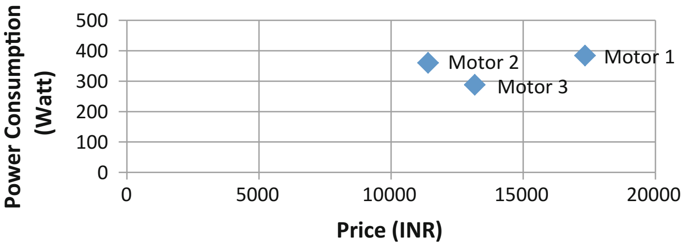

Fig. 7 Results of multi-attribute analysis, performance versus price of the system

4 Future Perspective

MBSE application and SysML as its enabler helps develop a master model that documents requirements, architecture, behaviour and design decisions, and will allow common, consistent and complete analysis of a system. In the same model system level attributes to further characterize the elements as well as those originating from the system context can be added. This approach is quick and allows trade studies in initial stage of design to study families of design alternatives and make valid design choices. SysML allows systems thinking by enabling efficient communication of concepts and description of different aspects of system of interest and their inter-relationships. Co-analysis with solvers and simulation tools helps evaluation of system level properties and emergent behaviours. This approach allows help with documentation and reuse of the documentation for future analysis.

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Conceiving and Applying Relationship Models for Design Strategy

Terence Fenn and Jason Hobbs

Abstract In this paper a new framework for problem solving in design is presented that positions the use of relationship models, in the context of design strategy, as a tool for the retention of synthetic integrity. A brief overview of complex problems in design with a specific focus on the creative leap from research analysis to design strategy is provided. The paper then introduces the fields of Strategy and Experience Design and demonstrates how, when applied together, they can assist in solving problems in a human-centered manner. Relationship models are then introduced and briefly discussed in context to Customer Relationship Management theory. Lastly, a template for creating experience-led relationship models is presented and exemplified. The example demonstrates how the overall framework presented in this paper ensures the synthetic integrity of the design.

Keywords Design strategy · Experience design · Service design · Relationship models

1 Introduction

Design research is only as valuable as the ability of the insights generated from the research to impact the solution in a meaningful manner. While there are many factors that may positively or negatively impact on the quality of research findings, this research paper is concerned with ensuring that the insights generated, meaningfully and explicitly, inform the design response to the framed problem.

'Synthetic integrity' is a term we introduce to describe the relationship of the resultant design solution to the research insights which informed it, whereby a favorable outcome is one in which the abductive thinking results in solutions that are both creative and/or innovative as well as relevant to the originating problem context.

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While abductive reasoning has long been considered to be the defining logic of design for ideating alternative product/service solutions, complex problems typically require a strategic consideration before ideation can occur. Resolving complex problems therefore requires abductive reasoning both at the level of ideation as well as at a strategic level, however knowledge and know-how concerned with the explicit conceptualization, modeling and communication of synthetically-driven design strategy[1] is elusive.

Relationship models[2] (RM's), as applied in this paper, are visual models that describe the desired nature of the relationship that an end-user may ultimately experience with an organization, product or service through a variety of factors.

In light of this, this paper will present a framework for the application of RM's, where human-centered design imperatives, strategic models and Experience Design models are merged, to ensure synthetic integrity in the design of solutions to complex problems. The aim of this framework and its associated tools (the experience-led Strategy Framework and Relationship Model) is to enable students and designers to develop clear and considered strategy based on and in response to complex problems in a manner that firstly, inherently reflects people's needs, and secondly, applies the strategy in a meaningful manner, through the use of RMs, in the ideation of design solutions.

2 HCD and Designing for Complexity

Human-centered design (HCD) is used in this paper to broadly describe philosophical and methodological approaches to design that are concerned primarily with users and their contexts of use during the research, conceptualization, ideation, implementation and reflective phases of a design solution [1]. While many authors [1–5] have provided nuanced accounts of HCD, this paper will only provide a basic introduction to HCD in order to discuss its fundamental characteristics. For this purpose, IDEO's[3] Three Lenses of Human-Centered Design Model, Fig. 1, is adequate.

The Three Lenses presented in the IDEO model suggest that when resolving problems, the designer should first seek to generate solutions that are *desirable* to people, in that the solution meets the their needs; *viable*, in that solutions are financially and environmentally sustainable, and; *feasible*, in the sense that the solution can be produced on a technological level, that the technology is appropriate

[1]Design Strategy is used here in the sense of the application of design philosophies, methodologies, processes, methods and tools in the formation of other forms of strategy (such as organizational strategy, business strategy, product or service strategy, etc.).

[2]As opposed to the use of term in computer science as it relates to entity–relationship (EER) models for conceptual data modeling.

[3]IDEO is a global design firm well known for popularizing HCD and Design Thinking [6].

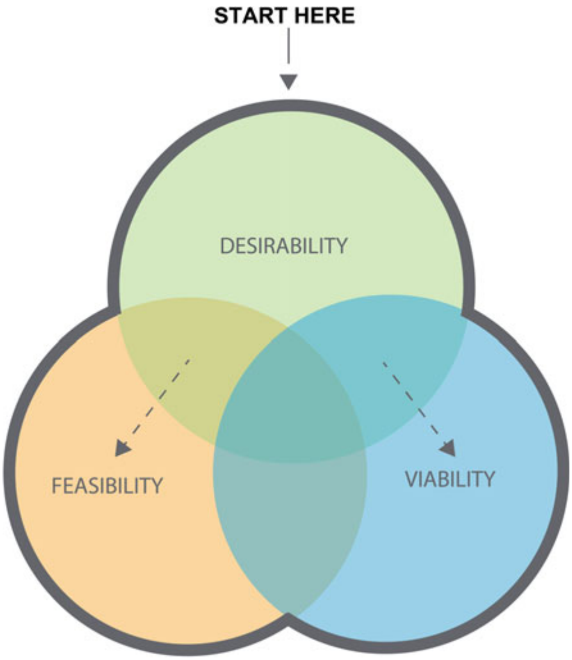

Fig. 1 IDEO's model showing the three lenses of HCD [5]

for the people who will use it, and lastly, that the solution is socially and culturally appropriate.

The IDEO model advocates that in HCD the initial engagement point for the design process are the people affected by the problem. This positions HCD as an inherently social activity that acknowledges and supports people's conceptions and desires in order to produce meaningful solutions [7]. Understanding peoples' problems is however a challenging process as societal problems can be ambiguous and hard to define, obscured in the complexity of social reality and offering no clear direction for resolution [7, 8].

These often highly complex design problems are often referred to as *wicked problems* as they must be 'tamed before they can be resolved' [8]. In HCD, resolving wicked problems requires three main activity phases[4] namely problem framing (developing an understanding of the problem), strategy (the designer's proposed intention for resolving the problem at hand in reference to their particular framing of the problem), and prototyping (the embodiment of the strategy through the various artificial interfaces that users' will interact with).

It is the position of this paper, that the design strategy phase is pivotal in the abductive transformation of research findings into actionable outcomes, and that RM's, as we will demonstrate, are a valuable tool for conceptualizing,

[4]These phases are evident in a number of 'design thinking' models for example Stanford, D School [10].

communicating, and ensuring the transference of synthetic integrity from research to solution.

3 Strategy and Experience Design

Although the purpose and practice of Strategy takes many forms depending on the discipline and context in which it is being performed, it is broadly understood as a high level intention to achieve particular goals under unpredictable conditions [9].

These conditions of uncertainty can range from, by way of example, contextual factors such as technology, society, environment, politics, economics and culture, to market factors (such as the competitor landscape), to the internal dynamics of organizations, etc. [11]. A further characteristic of strategy is that it operates over a long-term, and thus, sustainability is a key factor in the assessment of strategy for its effectiveness in execution [12]. It could therefore be argued that the skill in strategy development is the creation of a plan that is sustainable under conditions of uncertainty.

Rumelt [13] provides what he refers to as the 'kernel' of strategy, a generic 'underlying structure' [13:77] to any good strategy that "…leaves out visions, hierarchies of goals and objectives, references to time span or scope, and ideas about adaptation and change." [13:79]. The kernel is described by Rumelt [13:77] as follows:

1. A diagnosis that defines or explains the nature of the challenge;
2. A guiding policy for dealing with the challenge; and,
3. Coherent actions designed to carry out the guiding policy.

The 'diagnosis' refers back to our discussion of wicked problems and the requirement (in HCD) for understanding users and their context of use. The 'guiding policy' is informed by the 'diagnosis' and again, from the perspective of HCD, is the outcome of the synthetic resolution of the complexities of desirability, viability and feasibility. And 'coherent actions' provide a reframing of *what is* towards *what could be* by providing the requirements for what the design solution should provide.

Strategy development, in the absence of a human-centric approach, does not however always place the same emphasis on the user or customer as HCD. Where, for example, business strategy's objective is the sustainability of the business, human-centered design strategy's objective lies in improving the human condition. It is important to note that the two are not mutually exclusive. In fact, it is the merging of these concerns that has resulted in design's contemporary positioning as a tool for organizational and business development [14].

Experience Design focuses on the degree and character of the emotional engagement that users encounter during their engagement with technology, in order to fulfill their goals. While experience is a naturally occurring result of engagement and can be either negative or positive [15], the intention of Experience Design is to create 'preferred states'. Thus, 'positive experience' is regarded as the curation of the user's interactions with the solution in order to produce appropriate positive emotional responses [15]. Much of the current practitioner orientated literature [16–19] is typically concerned with the curation of user's emotional reaction obtained through interacting with a solution [20]. While this 'reactive' account of experience is of value, Hassenzahl [15], Wright and McCarthy [20, 21] argue that experience factors should be considered primarily in response to people's lived experiences. Thus, an 'appropriate' emotional engagement is one that is orientated within the larger life needs of the relevant users. Positive experience, Hassenzahl [15] states, is closely related to the fulfillment of need. Experience Design is therefore fundamentally concerned with exploring and supporting human need at a variety of levels. In essence, Experience Design is an appropriate theoretical framework for engaging with the desirability lens of HCD.

The *Three Level Hierarchy of Needs* model, Fig. 2 [15], borrowing substantially from activity theory [15:11], suggests that people's activities are motivated by need fulfillment. The model describes a hierarchical categorization for considering users' goals whereby users' instrumental activities are orientated by their aspirational motivations. From the perspective of the problem framing phase of HCD, the model suggests that a strong focus needs to be placed on addressing the motivational needs of users.

For this purpose, and as depicted in Table 1, Hassenzahl provides a list of the ten psychological motivations most important for satisfying human need that is commonly presented in clinical research. Hassenzahl states that these psychological motivations are not always all present or equally intense. However, they do provide a valid categorical framework for identifying and organizing human motivation. On a practical note, it is our experience that psychological needs do tend to present themselves during research that probes 'why' users perform certain actions or goals.

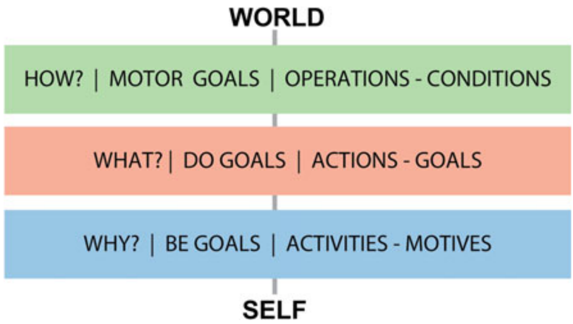

Fig. 2 Adapted from three level hierarchy of needs, Hassenzahl [15]

Table 1 The ten most common psychological needs, described by Hassenzahl [15]

Autonomy/independence	Competence/effectance	Relatedness/belongingness
Self-actualization/meaning	Security/control	Money/luxury
Influence/popularity	Physical thriving/bodily	Self-esteem/self-respect
	Pleasure/stimulation	

Table 2 An experience-led strategy framework

Rumelt's 'kernel'	Principle
"A Diagnosis that defines or explains the nature of the challenge"	Users are unhappy because certain psychological needs are not being met. This is because of x, y and z. Therefore, they are leaving, not buying your product, complaining, rioting in the streets, etc.
"A guiding policy for dealing with the challenge"	If we change x, y and z to a, b and c then users will feel differently and act differently. I.e. they will stay with us, buy from us, compliment us, stop rioting, etc.
"Coherent actions designed to carry out the guiding policy"	A, b and c should address user's needs by providing the following…

If we wish to benefit from what Experience Design has to offer by deeply understanding users and their context at the design strategy level, then addressing psychological motivations needs to be centrally embedded into design strategy with the intention of manifesting solutions that provide positive experiences.

Table 2, demonstrates how the worlds of Strategy and Experience Design can effectively come together where Rumelt's 'kernel' [13] occupies the left column, and the use of emotional drivers appears in text in orange and provide the synthetic integrity required by HCD.

It is important to stress that 'coherent actions' are requirements and are not the design solution itself. This creates a space for ideation and exploring the best possible design solutions that will answer the 'guiding policy' and the requirements set out by the coherent actions.

However, from a pragmatic point of view the question now becomes: how does one ensure that the synthetic integrity of the strategy is embodied in design solutions?

4 A Framework for Relationships Models in Design Strategy

4.1 Conceptualizing Relationships in Business and Design

Customer life cycle models have emerged from the field of Customer Relationship Management (CRM) are a tool applied in Customer Lifecycle Management. Customer life cycle models articulate and communicate the various phases customers encounter when considering, purchasing and using products, as well as the related organizations modes and methods of ensuring customer transition

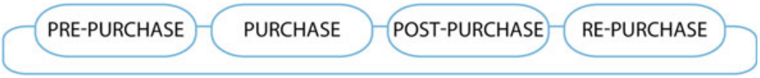

Fig. 3 A generic business lifecycle model

effectively through their service offering [22]. A basic example of a generic life-cycle model is illustrated in Fig. 3.

It is of interest to this paper that models of this kind have, over the last decade or so [23], started to emerge in design fields such as Service and User Experience Design, particularly to their application in customer journeys maps.[5] Nonetheless there is very little description in design literature that explains how models such as these should be conceptualized and applied in design.

The example below, Fig. 4, highlights where we can observe a lifecycle model being applied in the construction of a customer journey map.

It is the manner in which models for relationships between customers and organizations (such as lifecycle models) manifest in design tools (such as customer journey maps) as a means to bridge strategic concerns and design solutions.

RM's describe the desired nature of the relationship that an end-user may ultimately experience with an organization, product or service through a variety of factors (which can include the channels through which interaction occurs, people, processes, places, time, etc.). Importantly, the RM does not describe these factors but rather operates as a guide to how these factors should be curated to produce a particular experience for the end-user. To use lifecycle models as an example, the lifecycle is the relationship model, which is progressively 'fleshed out' in customer journey maps and other ideation tools used in design. RM's in HCD are understood to emerge from a deep understanding of user/customer needs, wants and desires in the context of society and contexts of use and being, rather than imposing business or organizational models onto users/customers.

In this sense, the term 'relationship' is used quite literally: should we design a mutually beneficial relationship with longevity? An expedient relationship? A short or long relationship?

It is worth sharing the perspective of the Service-Dominant Logic of Marketing to highlight the importance of RM's. The notions of value-in-use and the co-creation of value [28] emphasize that assigning value to the exchange of goods for money is to misunderstand that the value only manifests in the use of those goods by the user. For example, a business may assign a monetary value to the sale of a nail, however, the customer only realizes the value when using the nail to hang a picture in her living room. This example makes the point that value exists in-use and we would argue that it is in this co-creation of value (the business and the customer working together to 'hang the picture') that relationship manifests.

[5]In the field of practice customer journey maps are also known as 'experience maps', user journeys, or just 'journeys' [24–27].

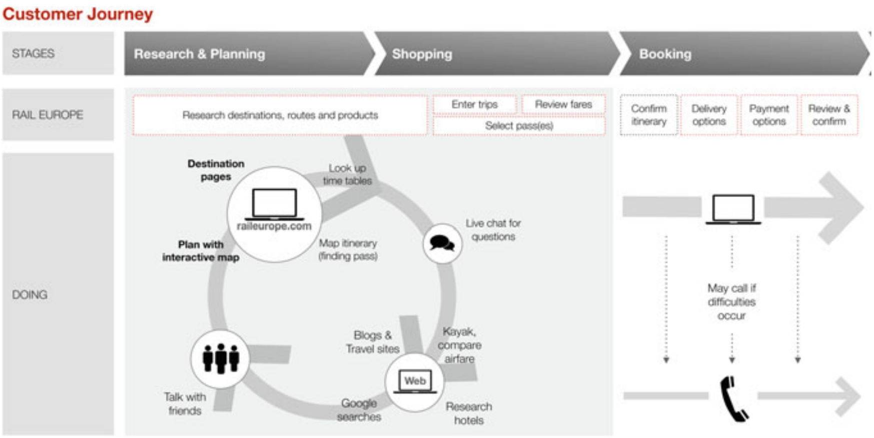

Fig. 4 Section of adaptive path's 'The Rail Europe Experience Map' [24] where a section of the lifecycle model is evident at right of 'STAGES'

Implicit in the points just made is the idea that RM's, when appropriately applied, can assist in conceptualizing and communicating the strategic pivot between understanding what users and customers need (in context, and arising from research) and designing the solution. To this point and following on from the experience-led Strategy Framework presented in Table 2, page 6. We present a template for experience-led RM models (Fig. 5) that:

- Describe the most appropriate psychological needs required to fulfill users' motivations.
- The 'coherent actions' that contextualize the psychological drivers in relationship to the 'guiding policy' of the strategy.
- Lastly, the emotional responses experienced by our users as a result of the designed solution (the 'reflective' experience drivers).

Experience-led RM's ensure that psychological motivations become the design solutions' reason for being and they orientate experience *as* strategy. In the concluding section we will briefly describe an example of the experience-led Strategy and RMs in application.

4.2 Applying Experience-Led Strategy and Relationship Models

The framework described in this paper has been applied in numerous practitioner workshops, as well as in design projects (including that of a major financial institution) by the authors. Furthermore, the framework is being taught at 3rd and 4th year level by the authors in the Department of Multimedia, University of

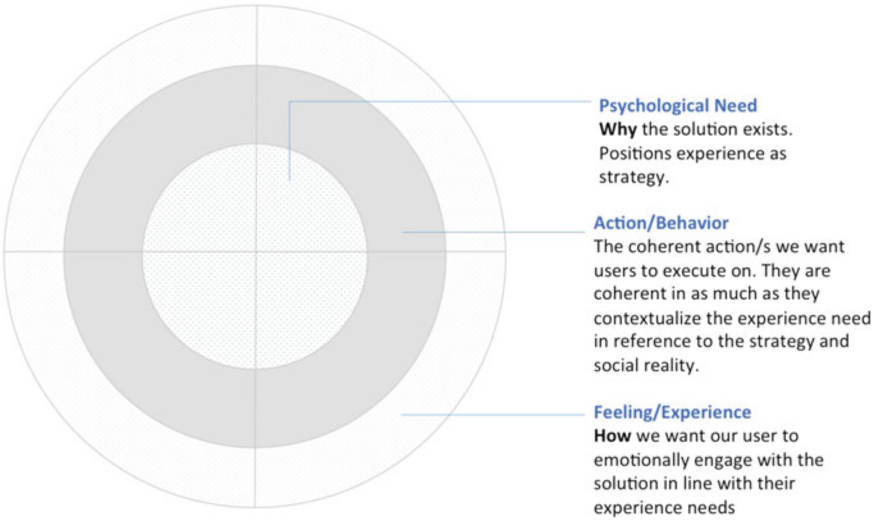

Fig. 5 A template for experience-led relationship models

Johannesburg. What follows is an example of the application of the framework by a 4th year Interaction Design student (named Chanel) at said university. This student was one of 27 that participated in the various workshops, which we used in order to establish the validity of the tools presented in this paper.[6] In preparation, all students had completed in-depth research focused on the ecology of a wicked problem and identified the key psychological needs of users through secondary research and rich qualitative interviews. This particular example addresses the problem of the high dropout rate of 1st year students at universities in South Africa. Chanel's strategy framework follows (Table 3):

Through the student's work the synthetic integrity of the research findings can be identified. While this is noticeable in the strategy framework due to its overt design, it is in the RM that the strategy, in terms of the cohesive actions and the psychological needs, orientate the experience drivers (Capable, Confident and Supported). The value of this becomes apparent when we see on the right hand side of Fig. 6 how the student has used these experience drivers to guide the ideation of potential solutions. Thus, the strategy, based on research insights, can be described as making a meaningful and explicit contribution to ideation and in all likelihood final solutions.

[6]21 students responded to a qualitative questionnaire asking whether are not they felt the strategy and RM tools improved their understanding and ability to apply strategy in their own design work. All students responded favorably, however, the authors felt that verification of the effect of the tools could be better assessed on the completion of the design projects.

Table 3 Chanel's strategy framework

The diagnosis: School leavers are left feeling uncertain about study choices **because their need for** *Independence, Self-actualization* and *Control* **is not being met**
This is because of: (a) Poor access to information (b) The university's website being difficult to navigate without prior knowledge or assistance (c) Lack of awareness of available university resources related to career development
The Guiding Policy: **By** making information about study choices more accessible and easier to understand, students will achieve *Independence, Self-actualization* and *Control*, **and thus** students will make more informed study/career choices
Coherent Actions: Students **will feel** *Independent, Self-actualization* and *Control*
If we provide: (a) Greater access to information about the repercussions of study/subject choices (b) Social and peer-to peer support regarding awareness of university resources related to making career/study choices (c) Ensure navigating through university resources is easier (relating to career/study choices)

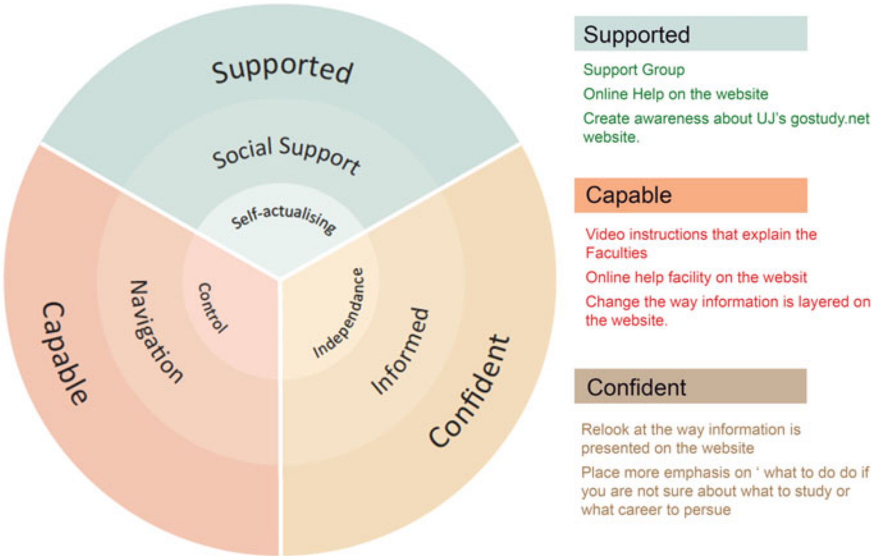

Fig. 6 Chanel's relationship model

5 Conclusion

This framework outlines a number of key positions that collectively seek to ensure that the synthetic integrity of a design solution is ensured from research through to solution crafting. These positions are orientated within a human-centered/

experiential framework which argues that it is peoples' life motivations that are the essential (but not the only) considerations for resolving complex problems and as such human experience should drive design strategy rather than be the outcome of product use. To this end, the framework offers the means for RM's to be applied as a tool to pivot from design strategy into design solutioning while foregrounding and thereby ensuring synthetic integrity.

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Empower the Future: The Inside Story of Building Creative Space for Sub-urban Kampong's Children

Martin Katoppo and Phebe Valencia

Abstract Imagine design as generator. Throughout our practice of empowerment we believed that design should be the champion of generating change within the community, thus we based our thinking and action under what we called DAG (*Design as Generator*). We then developed design-research-action methodology for DAG and to put design in the front line of empowerment practice. It combined PAR (*Participatory Action Research*) and DT (*Design Thinking*) under the MMR's (*Mixed Methods* Research) *Sequential Embedded Experimental* model. These complex processes resulted on three strategic themes that DAG developed for empowering community called 'Memory', 'Hope' and 'Sense'. The paper will focus on discussing 'Hope' as it aimed on constituting the future, in which DAG believes that the children will be the leading role shaping it within the community. The paper will tell the story on how it would be done through a community design project, initiated by DAG called '*KaKiKuKeKo*' project ('Creative and Collaborative Gathering for Our Kampong') held at suburban kampong in Southern Tangerang, Banten, Indonesia. It aimed on activating the children creativity through their playing and improvement of their reading activities. It then would be translated and designed into space, in which in its process it would be an active collaboration and participation with the children itself. This paper is about their hope and story glancing creatively into the future.

Keywords DAG (Design as Generator) · 'Hope' · Children · Creativity · Participatory design

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1 Introduction

Imagine design as generator. Throughout our practice of empowerment we believed that design should be the champion of generating change within the community, thus we based our thinking and action under what we called DAG (*Design as Generator*). DAG started as an idea in 2012 that developed into a specific design-action-research method. It was put into action from 2013 until now in several urban kampong areas in Tangerang, Banten and Depok, West Java, Indonesia, as well as in several remote villages in Kalimantan, Indonesia. However, many of DAG programs were being focused in Kampong Pondok Pucung, a suburban and remaining native kampong adjacent to mega modern real estate located at South Tangerang, Banten, Indonesia. As a remaining native kampong, a rural area surrounded by modern development, the kampong offered interesting and warm social relationship, nuance with traditional ingenious culture mixed with many religious based activities. On the other hand, the physical condition of the kampong showed the usual face of urban kampong marginalized by modern development. It is a cluttered development with lack attention to healthy environment and improper infrastructure (Fig. 1).

In 2014 we initiated design aimed for Kampong Pondok Pucung's children. At that time we proposed *Taki—the community (sustainable) sensory garden*. It was planned to be a garden built by, with and for the community especially for the children. It would not only serve as playground for the children, but also emphasized in educating and injecting healthy environment awareness for the entire community member. The garden initial plan would borrowed an empty lot owned by one of the local clan [1] (Fig. 2).

However, after 2 years of negotiating and many design revisions, the owner finally disapproved to lend their empty lot to be used for *Taki*. Our evaluation showed that DAG specific method at that time was not developed and put to test enough, especially at the initial stage. It meant that *Taki* design was developed more from observation analysis, rather than actual engagement and active participation of the community. Thus the design result was still in stage of object consultation rather

Fig. 1 **a–c** The kampong existing social and physical conditions (*Source* Katoppo, 2012–2015)

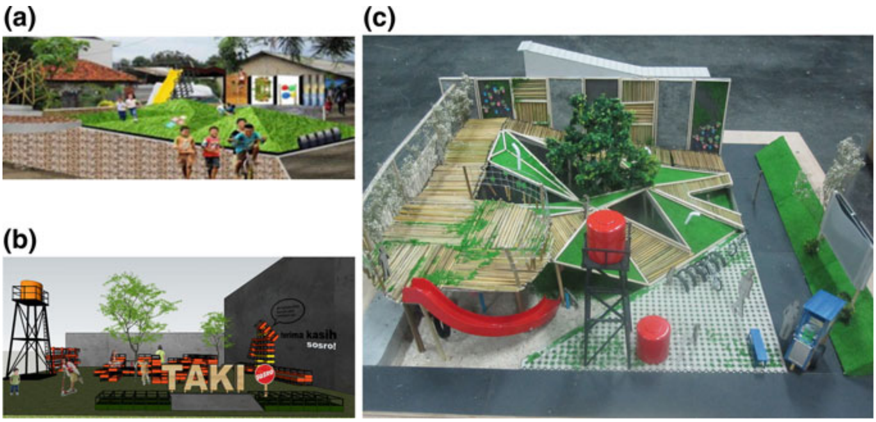

Fig. 2 **a–c** '*Taki*' design alternatives, 2013–2015 (*Source* Katoppo, Valencia: 2013–2015)

than as subject collaboration with the community. Moreover, the children as the primary stakeholder in this project were not having more active involvement in the design process. To add bitter fact to the project, now the empty lot had already been built by the owner to become rented house for temporary dweller. Nevertheless DAG team refused to give up building creative space for the children. We then change the strategy to intervened small idle and unused spaces owned by locals throughout the kampong to be change into creative spaces for children. This is the story behind it.

2 The Research Methods

As mentioned above, we developed a specific design-research-action methodology for DAG and to put design in the front line of empowerment practice. It combined PAR (*Participatory Action Research*) and DT (*Design Thinking*). Participatory Action Research (PAR) was chosen because it gave a dynamic cyclical motion between the act of conducting research and action aiming for change in the community [2]. PAR worked within the community social dimensions through 3 phases of Look-Think-Act [3]. Design Thinking (DT) with its HCD (Human Centered Design) toolkit for social innovation project fits well to establishing the bridge between PAR-LTA social dimensions to architecture 'design' dimensions. DT-HCD were also worked in three stages, which are: (1) **H(ear)**—listening to what is needed and where the design teams blend with the community, collecting stories and inspirations from the locals; (2) **C(reate)**—in which the design teams work collaboratively with the community in form of workshops, design *charrettes*,

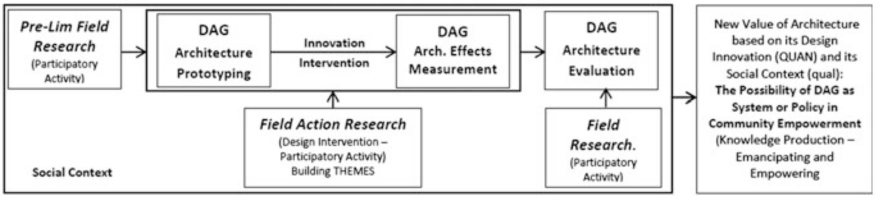

Fig. 3 DAG design research methodology and action (*Source* Katoppo, Sudradjat: 2014)

translating stories and inspirations gathered from the first phase into frameworks, opportunities, problem solving and solutions, and the making of prototypes; (3) **D (eliver)**—where all stakeholders gather and design the sustainable implementation plan [4–7]. To formulate PAR and DT-HCD in a more implementable design-research-action method we used Mixed Methods Research (MMR) model: *the Sequential Embedded Experimental Model* [8].

The alternative methodology will give opportunities for the designer-researcher to moves along quantitative sides of designing and prototyping, while in the same time qualitatively developed participatory and collaborative endeavors as an experience for every stakeholder involved in the process. The proposed mixed methods will give new values to design, in virtue of its innovation and its response to social context [9] (Fig. 3).

The complex processes within this alternative methodology resulted on three strategic themes that DAG developed for empowering community called 'Memory', 'Hope' and 'Sense'. 'Memory' concerned on identifying values—or about re-enacting the importance of recognizing the past, thus it would be more connected to the adult community member. 'Sense' concerned on intervening the physical space—or about responding to what the community member experienced their spatial arrangement now. 'Hope' aimed on recognizing the community wishes towards their environment, thus constituting the future. In this sense DAG translated 'Hope' as strategic themes focusing on the young member of the community, the children themselves that will be someday, the leading role in the community.

These 3 strategic themes then translated into interventions in forms of various design prototypes, which were implemented as medium for pushing the emergence of social change and empowerment. Each design intervention prototype would be done in stages of design, pre-test, action and post-test. In Kampong Pondok Pucung itself, design intervention prototypes were already been built and tested since 2014. 'Memory' was translated into design interventions called '*TATITU*' (a designed greenery initiation), while 'Sense' was translated into an initiation called '*Nabung Aer*' (a simple 'green' low technology for organizing organic domestic waste and rain water absorption system). 'Hope' was translated as '*KaKiKuKeKo*' project, that acted as continuation from *Taki* project that aimed on building creative spaces for the children in Kampong Pondok Pucung. The paper would focus in 'hope' translation, the '*KaKiKuKeKo*' project (Fig. 4).

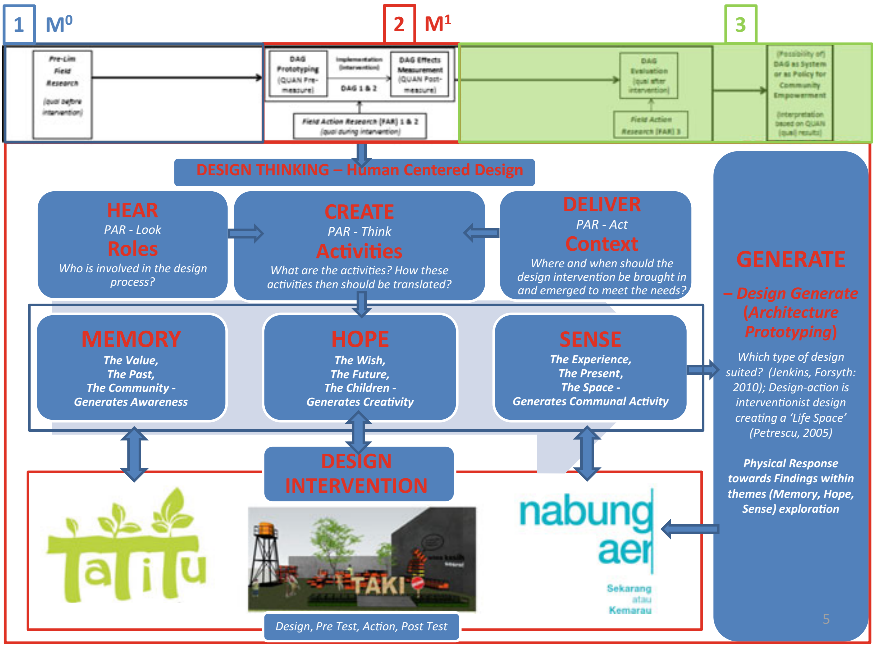

Fig. 4 DAG development of themes and design interventions (*Source* Katoppo: 2015)

3 The Inside Story of '*KaKiKuKeKo*' Project

Translating 'hope' started with preliminary field research in which consisted of observations and engagement with the children of Kampong Pondok Pucung through several creative playing activities. It were designed to build their creativity and their sense/awareness towards a more hygiene and 'green' environment (Fig. 5), while in the same time gave the researcher accessed to gather data from the children. With these approach, the preliminary research findings shown that: (a) the children would played outside and be very physically active in their games, (b) The children would also play in any open spaces that they could find within the kampong's area, even if the spaces were used as garbage dumping place, and (c) they would creatively use their amazing imagination to respond to these limited situations and turning it into playful space, however (d) the research also shown that the children has lack interest of reading, mainly because they have limited access to books and literatures.

Upon seeing these facts, DAG team then initiated a creative community design project for the children called '*KaKiKuKeKo*' project. The title used vowels as reminiscence to reading learning process, while the letter K was indicating Kampong (Ka), Ki (*Kita*—our), Ku (*Kumpul*—warm gathering), Ke (*Kreatif*—creative) and Ko (*Kompak*—collaborative): 'Creative and Collaborative Gathering for Our Kampong'. It aimed on activating the children creativity through playing

Fig. 5 **a** 'Color Your Kite' day, **b** 'Coloring and Cultivating' day, and **c** 'Making Recycled Toys' day (*Source* Katoppo and Valencia: 2014)

activities, while in the same time try to improve their reading interest—as DAG team believed that there is strong connection between creativity and access to read. It then would be translated and designed into space, in which in its process it would be an active collaboration and participation with the children itself.

'*Ka KiKuKeKo*' project itself, was part of larger program called 'Citizen Urbanism' initiated by *Rujak* Center for Urban Studies (RCUS) and Ford Foundation in 8 cities to produce creative initiation within the community to define their own dwelling environments as part of building the city. In its development the project also involved *daun* foundation that cares for building creativity towards children; lecturer and students from Interior Design Department, Visual Communication Design Department and Psychology Department of Universitas Pelita Harapan (UPH).

3.1 'KaKiKuKeKo' *PHASE 1: Mapping the Children Playing Activities*

In accordance with PAR-LTA and DT-HCD steps, the project started with the phase of L(ook) and H(ear). These phases were translated into ground-mapping of children playing activities shown in Fig. 6.

It showed that to know more about the children, we have to build a more comprehensive mapping of their playing activities. The new map should indicate what playing activities still being played by the children and where would be the location of these playing activities in the kampong. It would be acted as pre-test for the project and as cue to build the right creative design interventions for the children. Thus, the production of the new map must be done collaboratively with the children. To ensure that the process of data gathering would be valid, DAG team then co-operate with psychology experts and video documentary lecturer and students from Psychology Department and Visual Communication Design Department, UPH. Psychology experts were asked on how to interact with the children and extracting data from their activities, while documentary video was

Fig. 6 Initial mapping of the kampong’s children playing activities (*Source* Katoppo, 2015)

chosen as method of documentation because it would effectively record physical interaction from the children playing activities. All parties then agreed that the children participated in the mapping process, should do the playing activities naturally and at the location that they usually used.

The data gathering and documentary took only one day to be done, as we gathered around 50 children and divided them into groups to play in accordance to their own preferences. Each group was accompanied by 1 playing facilitator, 1 researcher to inscribe the playing activities and 1 video documentary personnel recording it (Fig. 7).

Fig. 7 The mapping process (*Source* Katoppo, Valencia: 2015)

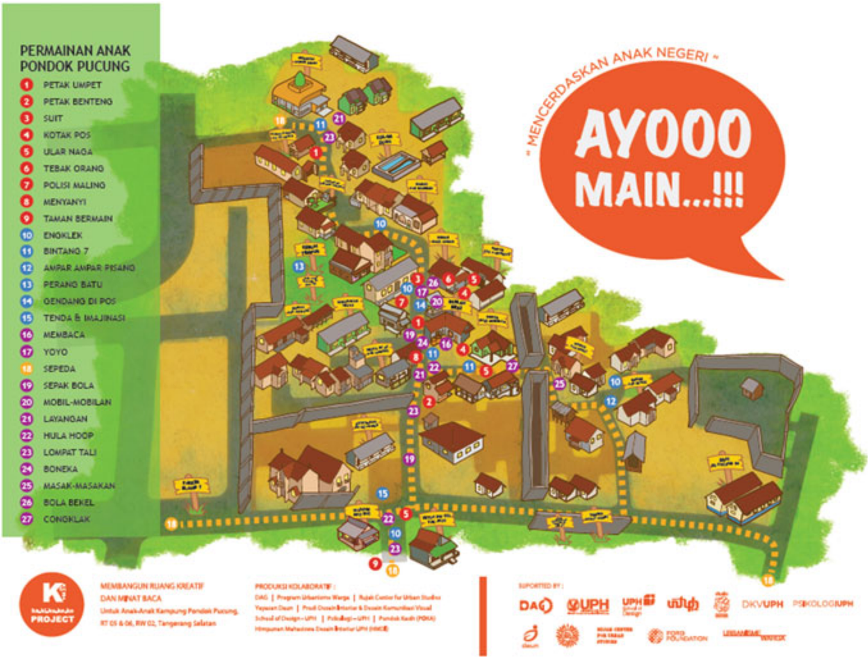

Fig. 8 Kampong Pd. Pucung children playing activities map (*Source* Katoppo, Valencia: 2015)

The team succeeded in mapping 27 playing activities with its locations, and with the helped of Visual Communication Design Department the new map was made visually interesting and interactive for the children as well as for the community member (Fig. 8).

The map was put to test and it became evident that the children loved it and used the map. They recognized their playing activities and its locations, while mostly get excited to search and identified the location in the map and then matched it with the actual location in the kampong. They also used it as plan to what and where they would be playing. DAG team noted that by using the map as identification, the children improve their reading activities as well as their own spatial connectivity to the kampong creatively (Fig. 9).

Fig. 9 The children used the map interactively (*Source* Katoppo, Valencia: 2015)

3.2 'KaKiKuKeKo' *PHASE 2: Prototyping the 3D Interventions*

The second phase of the project was in-line with the PAR-T(hink) phase as well as DT-C(reate) phase. This phase was responding to the findings from the data gathering process, the designed map and how the children and community members reacted to it. Thus, the next phase was to design 3D interventions through prototyping activities done collaboratively and with active participation of the children. For this purpose DAG team consulted psychology experts and design lecturer with anthropology background. The team collaborated on building the suitable participatory design methods for children to be able to build their own prototypes, especially on how they would engage with forms when doing playing activities. The discussion led to agreement that the children themselves must be the one that will actively build the prototypes of the 3D interventions. Thus the method of building the prototypes would be 'hands on' approach, where the children would be asked to imagine their playing activities and along with the locations and with some simple materials and tools (card boxes, plastic ropes, tapes and bamboo sticks) would build 1:1 scale model/prototype that responded to it. Although at first the team filled with doubt that the children could made the prototype, on the implementation day with the help of students from design department, amazingly all the children managed to build creatively imaginative playing space interventions. The process gave important findings to the team, which are: (a) the children mostly imagined confined space, where they can crawl or caved in, yet (b), they also love to be physically engaged when playing. They treated the prototyping process to channeling their exuberant energy, whether climbing and sliding or made competitive situations between groups (Fig. 10).

With all the data and ideas that we gathered from the children, DAG team collaborates with lecturer and students from Interior Design Department, started to design the interventions. The design team agreed that the children should have 3D interventions in the form of playing tools that will use all of their motoric skills, have a sense of competitiveness and have shelter form that allowing the children to

Fig. 10 The children design prototyping by themselves (*Source* Katoppo, Valencia: 2016)

Fig. 11 The design and feedback process (*Source* Katoppo, Valencia: 2016)

get under it—as they love to crawl and hide. The playing tools should also have chance to be multi interpret by the children, as to enhance their imagination and creativity. After the 3D models of the design interventions created by the team, it was brought back to the children and community members to be discussed for getting feedbacks.

In accordance to that DAG team also went into discussion with the community on searching a place to become a reading and creative space for the children embedded with the design interventions that we developed for the children playing activities. The discussion proven fruitful as one of the local clan from the community member agreed to give their terrace to be transformed. DAG team seen this as perfect opportunity as the terrace already has weekly activities for the children to learn and citing Muslim's Holy Scripture and it already belongs to the community member. Thus inserting reading and creative activities would be more at ease and more importantly would be more sustain (see Fig. 11).

3.3 'KaKiKuKeKo' *PHASE 3: Design Implementation*

Finally after the design process had already gathered some feedback, the design was built and implemented. This final phase was in compliance with PAR-A(ct) and DT-D(eliver) phase. There were 4 spaces that we intervene, in which 3 were use as creative playing spaces for the children and 1 was use as reading and creative space for the children as mentioned above. The creative playing tools was built as planned, in which occupy the favored location for the children and small idle, unused spaces owned and approved by the community member throughout the kampong. It went the same with the reading and creative space as explained previously, as it is located at the house's terrace of one the local clan. The process of building and constructed it was done altogether and collaboratively with all the stakeholders. In this case the community members, the youth, leadership of the community—as it was supported by the formal and informal leaders of the community, DAG team, the lecturer and students from Interior Design Department, UPH and even the children did not want to miss to be actively participated and helped the construction to build the creative design interventions.

4 DAG Conclusion: Becoming Light for Others

The post-test we conducted as part of program evaluation showed several important findings, which are: (a) The active involvement and participation from the children throughout the entire process proven to be effective as shown by the children enthusiasm towards the design interventions and the creative playing and reading space (shown in Fig. 12). Thus it could be concluded that the interventions suited the children well and triggered multi interpretations on how they should interact with it, and; (b) the interventions were approved and supported by the community members as they gave permissions to use their spaces. The approval indicated that the participatory process was successful—compared to *Taki* stories above. Altering strategy and engaging with all possible community members and stakeholders, instead of focusing energy towards selected community members and only to design process in this case, proven to be resulted in more pleasing ways for all. (c) The community responded by doing their own self-initiation design intervention after DAG interventions were done. The response could be seen as indication that the interventions succeeded in igniting creativity within the community member and how they translated it into their own (design) language of playing and creative space. It showed how they produce their own (design) knowledge (Fig. 13).

In terms of achieving the 'hope' goals as strategic themes that based the whole '*KaKiKuKeKo*' project activities, it could be seen as an opening discourse on how the community could actually build their kampong collaboratively, by and with their own imagination and creativity. With this project, the community acknowledged that it was possible for them to constitute their kampong future to become better environment. As for the children, in which were the main actor in the whole process of '*KaKiKuKeKo*' project, although we claimed that the activities within it

(a)

(b)

Fig. 12 **a** The participative construction process and **b** the design implementations and the design interaction with the children (*Source* Katoppo, Valencia: 2016)

Fig. 13 The community self-initiated design interventions (*Source* Katoppo, Valencia: 2016)

and the design interventions triggers creativity, it still needed more observations on how the creativity actually generated and how it develop more. This is also applied regarding the goals of increasing reading interest amongst the children. Thus DAG team acknowledged that although the interventions and the reading space were already there, it is at the utmost important that DAG and the community, especially the children, should keep on generating and encouraging activities to bolster creativity and to ensure its sustainability.

The research also intended to show that design have the potentials to empower and induce creativity within the community. Yet the truest meaning of empowerment, it is when the community produces their own design translation and knowledge. When it did happen, design is indeed liberating. DAG team is well aware that the goal is high and the method is still far from being perfect. However, the story of '*KaKiKuKeKo*' project showed a glimpse of what Petrescu (2005) had offered: the beginning of 'life space' generating—*where participation was no longer a question but had emerged as (natural) activities, leaving the space for others, the spaces of uncertainty, heterogeneous, fragile, indefinite, fragmented and multiple*. A catalyst space, where one needs to re-invent continually [10].

Acknowledgements DAG team would like to acknowledge: RCUS and Ford Foundation in its Citizen Urbanism project, *daun* foundation, lecturer and students from Interior Design Dept., Visual Communication Design Dept. and Psychology Dept. of Universitas Pelita Harapan (UPH); and all the community members of Kampong Pondok Pucung, especially the children.

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Representing the Effects of Product Architecture for Decision-Making in Conceptual Design

Timo Richter, David Inkermann and Thomas Vietor

Abstract The definition of the product architecture has a great impact on customer satisfaction, company strategy, and costs. Whereas these effects mostly become visible in later stages of the product development, most decisions on the product architecture are made early in conceptual design when allocations of functions to solution elements are determined. To support these decisions, many methodical approaches exist, for instance, for functional integration or modularization. However, a big part of those merely addresses single effects of the product architecture. This paper presents a comprehensive approach to draw correlations between targets derived from the specific development task and methods for product architecture design. Therefore, it contributes towards the structuring of existing methods in order to enable the designer to select most suitable methods for specific development tasks.

Keywords Product architecture · Conceptual design · Integration · Modularization

1 Introduction

Within the conceptual design, the designer is called to define the product architecture by allocating the function of a product to physical components [1]. Thereby, various product models can be used, representing information about the allocation of system elements of different concretization, e.g., sub functions and function

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carriers, and allowing deciding on its allocations [2]. These decisions on the product architecture have various effects on product properties impacting customer's satisfaction as well as company costs and strategic aims of a company.

However, existing methods for product architecture design are often set up with a specific purpose (e.g. controlling variety or reducing the number of parts) and focus on particular principles for product architecture design only, such as functional integration or modularization. Thus, product models merely represent information on specific effects. Therefore, the current research aims at the development of a methodical framework, enabling the designer to understand the wide range of effects of the product architecture and to define appropriate product models for design activities supporting specific goals. In this overall context, this paper focuses on answering the following questions:

- How do existing methods consider effects of the product architecture to the designer in conceptual design?
- How do product models of different concretization stages of the design process contribute to a comprehensive product architecture design?
- How can the designer be enabled to identify suitable product models addressing specific effects of the product architecture?

Following the structure of these questions, Sect. 2 will give a short overview of established approaches for product architecture design. In Sect. 3, the role of product models on different concretization stages will be examined regarding their given information for decision-making on the product architecture. Based on this, in Sect. 4, a new approach will be presented, enabling the designer to define appropriate product models for specific development goals. Finally, the results achieved will be summarized and discussed in Sect. 5.

2 Product Architecture in Conceptual Design

How do existing methods consider effects of the product architecture to the designer in conceptual design?

To support product architecture design, many methods exist. However, mostly, they focus on particular development goals and only consider specific effects. This section will highlight the scope of the product architecture decisions in conceptual design and its effects.

The product architecture describes the allocation of the product function to physical components [1]. Consequently, the product architecture defines in what way a component of the product interacts with others, for instance, by imposing geometry constraints or transferring forces, material, energy and/or signals to ensure proper functioning [3]. These interactions are mainly determined in conceptual design when based on functional structures and working principles, a principle solution (concept) is elaborated [4].

Defining the product architecture, two general strategies that are often referred to as mutually exclusive arise [5]. Firstly, functional integration aims at a reduction of the number of parts and/or an extension of the number of functions while sticking to the number of parts [6]. Secondly, modularization aims at clustering functions into modules while minimizing the coupling among the modules and maximizing the cohesion within the modules [7]. The decision on an appropriate strategy depends on the required product properties and has to be supported by suitable product models representing the effects of the product architecture.

Effects of the product architecture describe the relations between the characteristics of the defined product and its properties, c.f. [8]. Characteristics define the structure, dimensions, materials, etc. of the product. In product architecture design, the designer influences characteristics with the objective of fulfilling certain required properties in the best possible way. These properties describe the product's behavior and are related to stakeholders' interests, e.g., the customer or the manufacturer.

Like the required properties, the effects of the product architecture are also very wide ranging and can be assigned to various areas of the company [9]. However, besides a quantity of literature focusing on handling the wide range of effects of product architecture, most methodical approaches for conceptual design only consider a few of these and could be categorized after three main objectives: reducing variety (e.g., [10]), modularization for product-strategic reasons (e.g., [11]), and functional integration (e.g., [5]). Comparing objectives of these approaches, their considered effects show many overlaps and can be allocated to three main areas of impact (described by the authors more precisely in [12]):

- customer satisfaction, e.g., higher compactness or less weight through integration, higher adaptability or enhanced reparability through modularization
- company strategy, e.g., lean processes through less (integrated) components, higher flexibility and external variety through modular product systems
- company costs, e.g., less material consumption and high interdisciplinary development effort for integrated mechatronic solutions, less manufacturing effort and purchase costs through the use of standardized modules.

For product development, this wide range of effects results in the challenge of defining appropriate product models supporting analysis (evaluating effects on product properties) and synthesis (determination of the product architecture) as single product models only represents some of those effects.

3 Product Models in Product Architecture Design

How do product models of different concretization stages of the design process contribute to a comprehensive product architecture design?

To communicate a comprehensive picture of the effects of product architecture design, product models used in the design process are central as they supply the basis for decision-making. In this section, the use of product models in design in general will be highlighted, before a framework for structuring product models for product architecture design is proposed.

3.1 Progressing with Product Models

A product model (also referred to as design model) is a model of the product being developed, representing sufficient properties of the product in an adequate form to support specific design activities [2]. In product design, a large number of different product models is applied, for instance, requirements lists, function models, product structure models, prototypes, etc. These product models are often assigned directly to design stages. Thus, during the design process, several product models are used that merely represent a small part of all available information about the current design stage in order to support only those decisions to be made [13]. For instance, models of early stages do not represent geometrical arrangements or materials but the required logical behavior. Consequently, the design process could be described as a progressing from product model to product model—from problem to solution [2]. In order to choose appropriate product models, a thorough understanding of modeled properties and the modeling purpose is required [13].

Since product architecture integrates the functional and physical view on the product [1], product models supporting its definition require containing information of different design stages. For instance, when defining the module structure of a product, components have to be combined in modules considering function structures. An applicable product model is, for example, a Design Structure Matrix [14], representing components and their functional interactions. The same applies for functional integration, when, for instance, several function carriers are realized by one component [2]. In previous publications of the authors [15], it has been shown that several product models of product architecture design could be distinguished by its represented types of elements of different design stages and its represented effects. Thus, there is a need for an overarching framework.

In literature, approaches with similar objectives can be found. For instance, Otto et al. [16] present a generic sequence of steps of product architecture design in order to enable combining different methods of modularization in order to make use of the various potentials due to its specific focuses. Krause et al. [17] developed a methods toolkit to identify methods regarding, e.g., design for variety and life phase modularization. Similar to that, Ziebart [6] argues that functional integration requires a comprehensive understanding of different methods to be used and proposes a target model integrating objectives of various methods for functional integration in order to enable the designer to select suitable methods based on identified objectives. However, both approaches only focus on modularization or integration, while it is argued that objectives for both need to be considered simultaneously [1, 5]. For this reason, the approach of this research work is to describe product architecture design on overarching levels in order to allow structuring and goal-oriented application of existing methods for both modularization and integration.

3.2 Levels of Product Architecture Design

In order to systematize product models describing product architecture decisions, the authors have conducted a literature review, examining established approaches regarding their concretization level and considered effects. Extracts from the results have been presented in [11]. It has been found that system elements represented in the product models could be systematized by five levels of product architecture design, shown in Fig. 1.

Based on the established literature, five types of system elements on these levels could be defined:

- Functions describe the teleologies of objects, i.e. what they are for [18]. Functions could be of technical, semantic, symbolic or aesthetic type [19].
- Principles are basic laws from which effects to fulfill functions could be derived [4], for instance, physical working principles.
- Function carriers are technical elements to fulfill a function [4]. Described as working bodies and working surface pairs, they form a working structure.
- Components are individual physical parts from which the system can be assembled [20].
- Modules constitute a decomposition of a product into building blocks with specified interfaces, driven by company-specific strategies [10].

Within one level, system elements are linked by interactions, for instance, an energy flow between functions or physical connections between components. Between levels, system elements are linked by allocations, for instance, a function is allocated to a principle realizing that function. System elements from

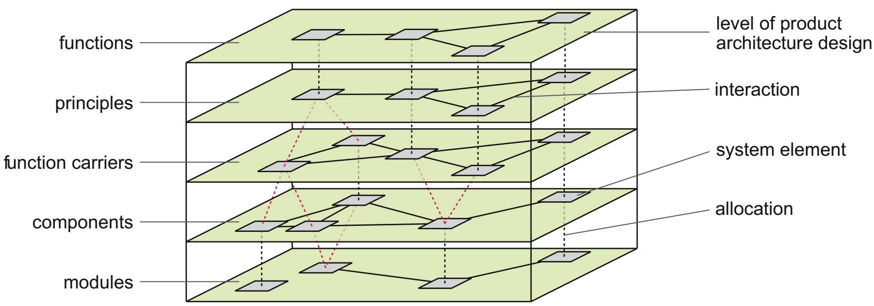

Fig. 1 Product architecture described as allocations between system elements of five levels

non-adjacent levels are also linked in this way over several levels. Thus, every function is allocated to at least one module as well.

The levels themselves are well known in product design. Besides several product models supporting decisions within one level (e.g., variation operations for functional structures), many product models exist to support decisions on the transition between the levels (e.g., deciding for working principles to realize functions, for instance, in a morphological box). However, an overarching concept with a focus on the explicit definition of the product architecture is missing. Therefore, the new approach aims at structuring existing product models regarding their contribution to product architecture design. Thus, principles for functional integration as well as modularization can be described in the same model in order to make use of the desired effects of both.

4 Representing Effects of the Product Architecture

How can the designer be enabled to identify suitable product models addressing specific effects of the product architecture?

As shown in Sect. 2, the product architecture affects a quantity of product properties. To be able to address these effects, the designer needs to identify the most suitable product models (Sect. 3). Therefore, in this section, a modeling approach is proposed to draw correlations between effects and product models.

4.1 Meta Model for Integrated Product Architecture Design

The basis for the determination of the most suitable product architecture in conceptual design is the designer's comprehensive understanding of its effects on different product properties. Product models can help to break down these effects by providing manageable information on the relation between design alternatives and product properties in order to support analysis and synthesis, see Fig. 2.

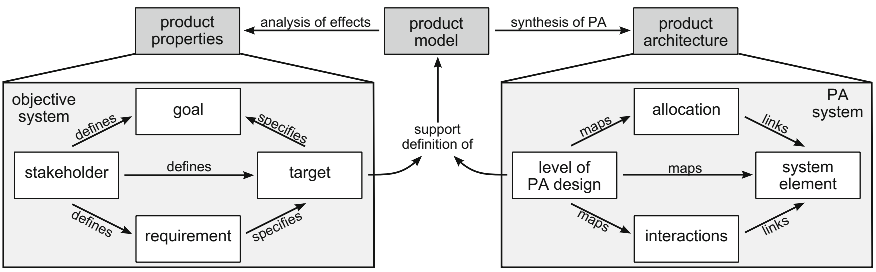

Fig. 2 Meta model for integrated product architecture design

However, the scope of a product model is limited. Therefore, its objective and extend of represented product information has to be defined clearly. Thus, the main idea of the presented approach is to increase the understanding of objectives (objective system) and the product architecture (PA system) to enable the designer to define appropriate product models to support design activities, see Fig. 2.

The PA system describes system elements and their allocations on the five levels as defined in Sect. 3.2 (levels of PA design). These levels provide the basis for the identification of appropriate product models supporting design activities. However, for that, development goals have to be specified within the objective system in order to create links to design activities. Therefore, a hierarchical modeling approach proposed by Stechert and Franke [21] is applied. According to that, requirements are modeled as specifications of targets and superior goals. In this way, objectives of the design task are described on three levels: goals, targets, and requirements:

- A goal describes the basic idea of what is developed, for instance, minimizing internal variety.
- A target specifies a goal as a principle to be applied to a specific level of product architecture design and describes objectives for allocation decisions of system elements in the PA system, for instance, reducing variety of used principles to realize the same function. (The target of this example is directly linked to the level of principles, since decisions on the allocations between functions and principles are made there.)
- A requirement specifies a target with concrete target values. Since every requirement is connected to targets and goals, a goal orientation of defined requirements is ensured, for instance, the desired number of applied principles to realize the same function.

In this modeling approach, targets are highlighted as the connecting element to the levels of product architecture design. On this basis, the designer is able to decide on suitable levels to carry out design activities to determine desired properties (for instance, by deciding for the level of principles to address the target of reducing internal variety). In order to support the definition of appropriate product models, existing product models, for instance, from approaches for functional integration or modularization, could be identified, that are categorized by targets and levels of product architecture design.

To demonstrate the application of the approach, Fig. 3 illustrates examples of goals (left), related targets (middle) and proposed applications of design principles in the PA system (right). The goals represent typical challenges of companies: Facilitating the testing prior to delivery of products, minimizing the final assembly effort of variant products, and limiting production costs by reducing the number of components. Related to these goals, four targets are shown that are derived from methodical approaches for product architecture design, e.g., the differentiation of function carriers in order to realize them as several components to be tested independently (c.f. [11]). Likewise, other targets could also aim at allocation principles of differentiation or integration (c.f. [6, 10]).

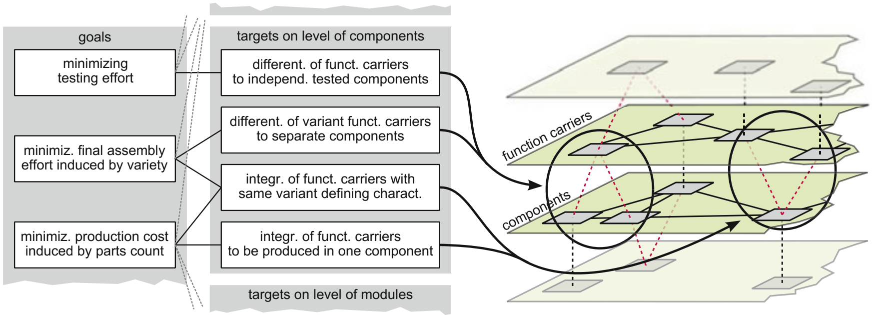

Fig. 3 Examples of goals and related targets aiming at allocation decisions on the components' level of product architecture design

This example only presents targets on the level of components, i.e., targets that aim at reconsidering allocations between function carriers and components. However, the dashed lines show that goals could be connected to targets aligned to several levels of product architecture design. For example, the goal of minimizing the testing effort could also be addressed by reducing the number of function carriers to be tested, thus, by integrating principles to be tested (level 2) into a reduced number of function carriers. Therefore, the proposed approach supports both the identification of suitable levels of product architecture design as well as the application of different targets within one level.

4.2 Application Scenario in Conceptual Design

The application of the proposed modeling approach in design projects require three steps to be executed: (1) Identification of goals related to product architecture design, (2) specification of goals by targets, describing concrete objectives for design tasks on levels of product architecture design and (3) definition of product models representing information for the implementation of the earlier defined targets. The application is suitable, in particular, for design projects with unclear objectives or various effects of product architecture decisions to be considered by the designer. In this case, steps 1 and 2 provide a basis for the explicit definition of appropriate product models.

Although the proposed modeling approach has not been implemented in a tool for industry use yet, its basic idea was used for several workshops in small and medium size enterprises dealing with the ideation of new product concepts. At this point, the example of the development of an air preparation unit will briefly be introduced in order to give an insight into the designer's problems in conceptual design when defining the product architecture.

Air preparation units are applied in pneumatic systems between the compressor and air driven devices. Since the air leaving the compressor often contains contaminations and does not have the appropriate pressure, it needs to be prepared. Therefore, air preparation units fulfil several functions such as filtering, regulating, lubricating, and other. Traditionally, these products are structured modularly, allowing a configuration regarding the required functions. However, the realized modularity of the air preparation unit entails certain disadvantages: The high number of interfaces between the modules causes extra costs for additional connection parts and results in a great installation effort for the manufacturer and customer. Furthermore, the robustness is noticeably reduced and the flow resistance is increased because of many redirections caused by interfaces.

Therefore, the application of the proposed approach supported the clarification of development goals affected by the product architecture. In doing so, targets could be identified aiming at differentiation or integration on the levels of principles, function carriers, or components, while previously the company had been considering a module definition only regarding main functions of the product. In this way, product models were created representing a decomposition of functions and its allocations to principles and function carriers, c.f. [22]. Using this product models and applying identified targets, new concepts were created in which solution elements for auxiliary functions were differentiated from modules fulfilling the main functions. Thus, for instance, the housing protecting the system against mechanical damage was differentiated from the modules for filtering, regulating, etc. and realized as one housing for all other modules. Therefore, by applying the proposed approach, the focus on product architecture design was expanded from previously only differentiation by including integration principles. In this way, development goals were achieved by decreasing the total number of parts and facilitating the mounting.

5 Conclusion and Further Work

The objective of the research work presented is to increase the transparency between effects of the product architecture and product models to support design activities in conceptual design. The focus was lain on the presentation of an approach for modeling the goals of product architecture design (as determination of required product properties). Thereby, targets that could be linked to levels of product architecture design are formulated, which has been presented in previous publications. This was stated as the basis for defining appropriate product models to support the decision-making on the product architecture in conceptual design.

Something that has not been shown in this paper is how exactly product models can be defined. Examples were given of using product models from existing approaches for product architecture design. It remains an unanswered question how the designer can be supported if no existing product models are appropriate for the specific design task. In this case, new product models have to be created; in doing so, it must be ensured that all necessary information is included to obtain a verified basis for decision-making. Therefore, further work aims at the elaboration of a catalogue of targets of product architecture design and the subsequent linking of product models. Therein, descriptions of targets should clearly define which information is essential for its implementation.

Moreover, the modeling approach needs to be implemented in a tool for industry. Hence, based on existing requirements modeling tools, a prototype based on SysML should be created. In this tool, a catalogue of goals and targets should be integrated, that were derived from literature and case studies in industry projects dealing with re-designs or new product developments in the fields of consumer goods, automotive engineering, and industrial mechanical engineering.

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Evolution of Design Briefs: Expressions from Professional Design Practice

Mamata N. Rao, Prasad S. Onkar and Deepak John Mathew

Abstract Professional design practice regards articulating design brief as an important step to begin a design project. Typically, the initial brief is given by the client to the designer/architect who may evolve the brief through several meetings with the client. Earlier research studies to understand design thinking have looked at the work of the designer with focus on 'conceptualization in design' with very few studies done to see the process of arriving at design briefs. This study aims to look at the process of clarifying design briefs in professional design practice. Our hypothesis is that a lot of early ideas for design solutions are established in the process of creating these design briefs. Designers from domains like Product, Interaction, Communication, Furniture and Architecture were interviewed in a semi-structured format, to understand the evolution of design briefs in their practices. In this study, it is observed that, designers set parameters in the briefing process itself which directs further design explorations and they tend to focus on *primary generators* in the design brief itself.

Keywords Design briefs · Professional design practice · Evolution of design briefs

1 Introduction

A design project usually begins with a design brief given by client/stakeholders to a designer. A design brief may have several components such as the aim of the project, requirements to be considered both in terms of user and business needs,

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target audience, budget and other technical/legal/ethical/environmental considerations.

Teachers in design schools emphasize *redefinition of design brief*, as it is believed to bring out original ideas. This redefinition can be regarded as '*problem frame* or *problem setting*' a term coined by Schon [1]. Schon [2] defines *problem setting* as the designer's frame of a design situation, where the designer sets boundaries and selects particular things and relations for his/hers attention.

A typical design process generally involves iterative phases such as design project briefing, research and analysis, conceptualization, design development and evaluation. Many of the earlier research studies have focused on 'Conceptualization (Design Schematic)' phase of design. Such studies have looked at the process of arriving at ideas/concepts in design where the designers have been asked to bring concepts for a given design brief in a specified time [3–5]. There are a few studies that have looked into the process of arriving at design briefs in professional practice [6–8].

Our study aims to look at the process of clarifying design briefs in professional design practice. Our hypothesis is that a lot of early ideas for design solutions are established in the process of creating these design briefs.

2 Background Study

A number of earlier research studies have focused on how designers go about solving design problems, get creative ideas for design solutions when given a brief.

Solution focused Design strategy is one where designer, when given a design brief visualizes solutions quickly instead of delving too much of time in the research and collection of information. There are two types of solution focused design strategy, (a) *Solutions based on primary generators*—here primary generators are ordering principles, one central idea without multiple exploration of solutions. Levin [9] found that designers created their solutions (partial solutions) quickly by latching to ordering principles. Cross [10] reports on examples of ordering form based on rectangular grids, teacups as seen in designer's work for town planning. Darke [11] interviewed well-known British architects about their intentions while designing local authority housing and found in her study that these architects latched to an early idea of having housing around a continuous terrace. She called such an early idea a *primary generator*. Rowe [12] studied the work of three urban designers and found that in all the cases the designers had to and fro movement between exploration of architectural form (*solution space*) and evaluations of program, structure and other technical issues (*problem space*). Rowe observed that the problem space was understood through solutions and the architects worked around *organizing principles* for massing explorations of building volumes. Lawson [13, 14] looked at how students of architecture and students of science would solve design-like problems under laboratory conditions and concluded that the main difference between the two groups is that the scientists tried to understand the problem better as compared to architects who focused on the desired outcome. The other design strategy is (b) *Solutions generated by changing problem frames*—Designer's bring in multiple solutions by framing and re-framing given problems. Eastman [3] asked experienced designers to 'Redesign a bathroom'. His study subjects created a series of solutions to learn more about the nature of problems and also discovered a requirement that was not mentioned in the design brief. Schon's [1] study describes a design review within an architectural studio between a student and a teacher (experienced practitioner). The design process takes a journey in which the teacher frames a new way of seeing the problem and explores solution possibilities through sketches in an interactive fashion. Cross [9] states on the interwoven relationship between problems and solutions solution is not a straightforward answer to a problem, but something that neither the designer nor the client dreamed of during briefing.

Christiaans and Dorst [15] study observed three different ways of Design thinking—(a) *Conventional based design thinking* (b) *situational-based thinking and* (c) *strategy-based design thinking*. Lawson and Dorst [16] further elaborate on the above three types of thinking: (a) *Conventional-Based Design thinking* one approaches design by using rules and convention based thinking such as planning grids, proportioning system and other geometrical rules, anthropometric rules (b) *Situation-Based Design thinking* one responds by studying the given design situation and trying to create an appropriate response to the particular setting. (c) *In Strategy-Based design thinking*, designers formulate a planned response by consciously designing the process and create the design situation for themselves.

The study by Maher and Tang [17] concluded that design process is *co-evolutionary*, where humans do a depth first search while computers do a breadth first search because humans have limited memory and powerful reasoning whereas computers have greater memory. Dorst and Cross [18] focussing on the *co-evolutionary design model* observed that in creative design, designers move from the notion of 'default' and 'surprise' within the problem space. The designers compare the current challenge with default project to check information to build up a general image of the assignment and look for surprises. The Integrated Model of Designing by Srinivasan and Chakrabarti [19] based on the co-evolution model combines process and product facets of design proposing activities, outcomes, requirements and solutions as elements of design. Helms and Goel [20] studied the problem evolution in biologically inspired design and found that analogies were used for identifying, formulating and transforming design. The study also showed that significant problem evolution occured independent of the generation of a new design solution for that problem. The work of Dorst and Cross [18] and that of Helms and Goel [20] has shown the significance of problem space in the evolution of design.

There are studies that have focused on 'Design Briefs' and 'Requirements in Design' focusing primarily on the problem space. One such study by Paton and Dorst [6] has looked at the briefing and reframing aspects in professional practice of Visual Communication Designers. The study categorized the briefing modes as '*Technician*' where the designer is brought towards the end (as the client knows what needs to be done); *Facilitator* where the client knows what they need but not what is required to achieve; '*Expert/Artist*' where the client has a partially formed idea on what is needed and designers can negotiate a brief in their own style as an Artist; '*Collaborator*' where the client and the designer collaborate on framing the project in terms of problem space and solution space. Lawson [8] discusses on a technique 'semantic differential' which enable clients to express their ideas about the spatial qualities with the interior designers without being specific on forms and materials. Lawson [21] stresses on the influence of legislations on the Design brief. The work of Worinkeng et al. [22] examines the influence of requirement types on the novelty and variety of design solutions generated. This study observes that a design problem brief when augmented with non-functional requirements would positively impact novelty and variety metrics.

This study aims to look at the process of clarifying and arriving at design briefs in professional design practice.

3 Our Study

Designers from fields such as Architecture, Product, Communication, Furniture, and Interaction design were interviewed to get an understanding of the process of arriving at design briefs in their practices.

The research questions the study aimed to look at were:

1. What is the process of arriving at design briefs?
2. How do they narrow down on aspects to be considered for design proposal?

The present study is based on interview data gathered from 10 respective field experts, viz. two architects, three interaction designers, five product/graphic designers. It was random selection with those who agreed to give interviews approached. The companies chosen varied in terms of size and scale of operations starting from small, medium to large corporations. Semi-structured interview method was employed to gather information on the processes involved in formulating the design brief in the above practices. The interviews were taken either as Face-to-Face (FTF) or Telephonic (Tel) discussions and in once instance was a Focus Group (FG) method and the discussion time was around an hour. The FTF and FG was taken in the offices of architects/designers. The designers/architects had to reflect on a typical design project and narrate on their process of arriving at briefs. Descriptive information about the firm and the work they had undertaken was sought from the firm's website wherever available. Otherwise the subjects were asked to send in additional material for supporting the discussions taken up in interviews. Only 3 of the total 10 interviews (this includes 1 focus group discussion) were audio recorded and for the rest notes were taken. For all of them detailed interview reports were prepared based on the audio recordings, the notes taken and additional information sought from their website or information sent across by them.

The data captured attributes such as Designer/Architect (Name, Contact, Education, Years of experience); Design firm vision and philosophy or specialization; Project type (Residential/Commercial, Product/Furniture, Interaction Design etc); whether the briefs were Written or verbal briefs; Typical or routine brief versus Innovative brief; Role in creating the design brief; Type of client and influence on brief creation; Process of evolving brief within the firm; Design services beginning and end; Components/Content of design brief.

For the analysis we examined the transcripts of the detailed notes for understanding design brief evolution, the process and design parameters shortlisted as design directions by the designers or architects.

4 Observations

We have reported our observations as cases. This section outlines the observations made during the study for the various cases taken up as part of the study. Tables 1 and 2 capture the attributes for each of the cases.

Case 1 (Arch01)
Profile: Architectural Firm 01 (Arch01)—Interview with Founder, an Architect. They mainly take up educational and Government projects with most of them taken up for warm climatic zones. Design briefs were mostly verbal.

Case 2 (Arch02)
Profile: Architectural Firm 02 (Arch02)—Interview with Founder, an Architect. The firm specialized in bringing 'Indian character' through the use of Indian architectural features and striving for 'Indian classical proportions'. In urban planning projects, Design briefs would require a lot of research, analysis and synthesis. Such Design briefs would contain: Definition of the project concept from the perspective of sustainability, socio-economic and use of available resources, rules and regulations of land-use, fire, services, parking, pollution control, byelaws. Design briefs were mostly verbal.

Case 3 (Des01)
Profile: Design Firm 01 (Des01)—Focus Group with 2 Founders and 2 partners; one Product Designer, One Visual Communication Designer and two architects cum furniture designers. Most of the time client's original brief contains what the company does and nothing much to do with the propositions. They make clients participate in development of briefs which helps them understand client's reactions on target audience, product positioning in the market and finalizing some keywords for inspiration and further take on Design. Design briefs are written

Case 4 (Des02)
Profile: Design Firm 02 (Des02)—Interview with Founder, a furniture designer who was a two-time winner of Red Dot award. The designer worked alone with 3–4 artisans. His main focus was to be able to create a furniture so as to contemporize in

Table 1 Lists the observations for the 7 cases studied research methods being face-to-face (FTF), telephonic (Tel) and focus group (FG)

Case	Type	No. of designers in firm	Project type	Given brief	Arriving at briefs
1	Arch01 (FTF at office)	1–2	Residential, educational, office/commercial	Basic space requirements	Alone for residential, with staff for large projects
2	Arch02 (Tel)	>5	Residential, museums, stadiums, home/office interiors, urban planning projects	Intent and space requirements	Mostly alone
3	Des01 (FG at office)	<5	Automobile, furniture, product, retail, graphics, branding, packaging	Mostly concept note with company's profile	Together with the clients
4	Des02 (FTF at office)	1 designer with artisans	Furniture design	Focus on materials, construction techniques for contemporary furniture	Himself based on artisans ability, the material and history of a place
5	Des03 (Tel)	<5	IT products	User insights, listing of requirements, feature list, tasks	The product management and user experience design team
6	Startup01 (Tel)		IT products	Developed from user analytics	Together with the founders
	Des04	2	Experience design and research consulting	Client's brief is recast	Together with the clients
7	Des05 (Tel)	>5	Software and interface design	1. Redesign and improving existing products	Marketing team
				2. Newer products	Based on newer technology demands and looking at parallel domains

Table 2 Lists on design briefs being written/verbal and the design brief parameters discussed

Type	Design brief highlights							
	Site	Climate	User	Product positioning	Legislations	Style	Reframing	Participatory design
Arch01	✓	✓			✓			
Arch02	✓	✓	✓		✓	✓		
Des01			✓	✓			✓	
Des02	✓			✓		✓	✓	
Des03			✓	✓				✓
Startup01			✓	✓			✓	
Des04			✓	✓			✓	
Des05			✓					✓
							✓	

a newer way. His research focuses on history of craft forms from the perspective of deciphering the character of place and craft form, abilities of the artisans producing craft work while proposing new designs. In his view market and user research is not important to his design as the requirements for furniture remain the same and have no influence on bringing innovative designs. Design briefs were mostly verbal.

Case 5 (Des03)
Profile: IT Company with Design Unit (Des03)—A User Experience Designer. This was a big corporate company known for creating Enterprise version software. Product Management team brings the initial requirement of project brief and hands it over to the User Experience (UX) team. User Experience Designer team conducts a 3-day participatory design thinking workshop where they work on brief, preliminary design ideas together with users using low fidelity prototypes initially and progressively improving them. Design briefs are written.

Case 6 (Des04 + Startup01)
A Startup (Startup01) + Design Firm (Des04)—Interview with the Founder a Product Designer who discussed on his small sized design company and his own startup with two other founders. For the startup the Design brief was developed based on several verbal discussions. Using analytics, they would redefine their brief every 6 months. The brief would change when they had to describe their product to software development or marketing team. For the Design firm a written the brief was developed together with client in a brainstorming session or a meeting called to understand client's context through primary and secondary research.

Case 7 (Des05)
IT Company with Design Unit (Des05)—Interview with Software and Interface Designer of a large, corporate, technology driven company. Their briefs are of two kinds one being Redesign based on usability evaluations and gaps captured by the Marketing Requirement Document (MRD) for their domain market. These are developed based on scenarios of concepts of usage, following the routine User Centered Design (UCD) process. The briefs for Design of Innovative products are conceptualized for newer technology products in markets that are not so mature. In such cases they look at inspirations for usages in parallel markets and contexts. They also capture stories in such cases and visualize concepts. Design briefs are written.

5 Discussion

Our study looked at the process of clarifying and arriving at design briefs in professional design practice. The various factors influencing the development of briefs are discussed in the following sub-sections.

5.1 Primary Generators in Design Brief

Designers or architects have tendency to focus on primary generators in the design brief itself as stated in *Case1* and *Case2*: "Bring Indian Character to the building" or "Site analysis and climate conscious approach". The design concepts generated around such primary generators were triggered in the Design brief. It was also seen that as experienced designers/architects, they seemed to have done similar kind of projects or have defined a philosophy for their work. Past projects or philosophy became a primary generator to define briefs. For example: The *Case1* (*Arch01*) who undertook mostly educational projects, large government layouts and had to strictly adhere to legislations and norms and incidentally most of these projects were located in warmer regions. This architect states "norms/legislation, site analysis for better wind and light, passive cooling are important elements in my briefs". The furniture designer, *Case4* (*Des02*) states design philosophy as "work with techniques, materials, traditional crafts and be able to contemporize." The *Case2* (*Arch02*) had a design philosophy and stated "Bring Indian character to my work using Indian architectural elements, traditional proportioning system and use of Indian typologies such as courtyards". Generating primary generators helped the designers/architects to narrow down the search space. This also brought clarity and focus for their work based on their philosophy/ beliefs or past projects. Many a clients' approached them knowing about their work and their specialty which became the designer or architect's identity.

5.2 Types of Design Thinking

In the formulation and evolution of Design briefs we found that there are designers/architects who showed:

Conventional—Based Design thinking—Architects/designers showed rule based thinking in the projects, like *Case1* (*Arch01*), *Case2* (*Arch02*) and *Case4*(*Des04*) discussed under primary generators such as creating designs based on past experiences, philosophy or a particular style, design of educational institutions based on arriving at programme, looking at norms and legislations as an important component of design brief. Although there was rule based thinking seen in exploring the design space in a particular style like 'Indian Character' or 'Contemporary' dealing in such spaces would involve high skill in being to translate these into the forms of buildings or furniture with great eye for proportions.

Situational-Based Design thinking—Designers and architects showed contextual awareness in their briefing process and brought in discussions related to users and trying to develop the design brief together with participating users. Examples are *Case1*, *Case2* where site analysis and thinking about architecture was based on local climate and materials in their briefs; as seen in *Case5* those who developed the brief together with the participant users in the user centered design approach. The design briefs could be seen from the perspective of situational awareness, but as this becomes applied many a times then it operates like conventional thinking, for example in the case of user-centered design or site analysis and climate conscious approach being applied for all projects.

Strategy-based Design thinking—This was seen in the briefs of designers who strategically questioned the brief given by the client and tried to strategically place the expected deliverables, questioned the existing approach to crafts and furniture design. In *Case3* (*Des01*) and *Case6* (*Des04*) the designers would not take the brief as is given by the clients and through a meeting would first try and understand what should be done and why?; then there was the furniture designer *Case4* (*Des02*) who researched the place 'Kashmir, its architecture, crafts, materials available, skills of artisans' and strategically positioned the furniture to have a contemporary flavor to increase the value perception for the product.

5.3 Reframing in Briefs

There were attempts to reframe brief in many ways, like the example of a startup company, *Case6* (*Startup01*) who reframed its brief every six months based on the analytics of usage. Their main question was "What is the next level of consumer experiences?" This same company gave briefs to different departments based on the expected deliverable from each of them for example: The developer was asked "Hack mobile phones to understand components for iterations". The reframing of briefs was also strategically taken up together with the client as seen in *Case3* (*Des01*).

5.4 Methods to Collaborate with Clients

There were different methods to interact with clients with increasing levels of participation such as presenting work at meetings and getting the brief clarified, making the proposed user to be part of the participatory design process, working together with artisans to create furniture and construction techniques, asking clients to collaborate and co-evolve together to agree on a brief that involves value proposition by questioning the client's given brief.

5.5 Written Versus Verbal Briefs

All these briefs stated were not always written briefs, many of these were verbal in nature and internalized processes except in the case of designers (*Case3*, *Case6*) who strategically wanted to redefine the briefs together with their clients in a session. These designers felt that it was important to have the client involved even in brief making so that the clarity developed on either side is transparent and through briefs they were able to develop clarity. In the case of the start-up and the architectural offices they preferred verbal briefs as it was quick and they were also reframing briefs based on digital experiences that changed with time.

6 Conclusions and Future Work

The study on design briefs showed that the design brief helped designers/architects narrow the search space and indicating probable design directions. We found that a lot of early ideas for design projects were established in the process of making these briefs. This is indicative that novelty and variety could be related to writing of design briefs, at the very beginning of design process. In all we found parameters such as site, climatic analysis; user context, product positioning, legislations, style, reframing given briefs, and participatory design discussed as part of design brief highlights. We found that parameters such as site analysis, climatic concerns and legislations were important for the architects; while product positioning and reframing were important parameters for Design firms. The user context was found to be an important parameter for most of them. This study would have relevance in design education from the perspective of developing design briefs and possible design directions. In future we plan to study the development of briefs as taken up in academic practice.

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The Effect of Idea Representation Techniques on Design Decisions During Idea Exploration Phase: An Exploratory Study of New Product Design

Purba Joshi and Sharmila Sinha

Abstract In this tele-visual age any information that looks televisual is automatically considered authoritative as stated by Lawson. Often the realistic visualization can override critical assessment of the content and stunt creative exploration. As stated by Wergles and Muhar realistic visualizations cause a "genuine excitement and anticipation" that can bias the decision makers. This paper explores the influence of various representation techniques on the decision-making during the idea exploration phase for new products. The paper presents idea explorations and representations generated during a design course. The documented ideas were evaluated by an expert panel for their implemental value and uniqueness. The evaluating criteria was determined and defined for setting a rating scale to demonstrate the influence of the representation techniques on the implement-ability and uniqueness of the ideas in the realm of designing new products. As mentioned by Abdelhameed, the media used by designers affects the process of design exploration and design thinking. Certain ideas can only be derived from specific tools and from individual use of media. Precise and realistic representations leave very little room for intended and controlled ambiguity, which is a prerogative for creative judgment in the idea generation phase. The findings can help to formulate a conclusive representation technique to help maximize creative exploration and outcome. This can further assist student and novice designers to develop effective and unique designs and overcome the constraints of realistic visualization during idea exploration. Even a roughly finished idea having deep explorative attributes has the potential of creative product output. The only point of concern in rating such ideas is that it requires experienced experts from the field to gauge the creative potential. Further work needs to be carried out to set certain steps of operation to maintain the flow of exploration, no matter what the mode of representation might be, as this investigation does not fall in the purview of the existing study.

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Keywords Representation techniques · Design decisions · Idea exploration

1 Introduction

In today's televisual age, photographs, computer graphics, virtual reality, walk-through models, videos and other visual mediums play a significant role. Any information that looks televisual is automatically considered authoritative [1].

Visual representations are an integral part of the design process and play a significant role in design decision-making. In the field of design, many new methods of representation like computer-aided sketching, Computer-aided modeling, virtual reality and 3D printed mock-ups have made in-roads. However the question arises; when different students use different mediums to represent their ideas, how does this affect their exploration, thinking and, finally their decision-making?

Abdelhameed [2] mentions that the media used by the designer could dictate the design outcome. Designers today use sketches, doodles, physical mock-ups and various CAD tools to visualize their ideas. In this paper, we are not comparing these tools against each other. From our experience, we have realized that these various manual as well as computer-aided tools exist and are used in coherence. A designer may use a specific combination of tools as per their convenience and proficiency but there is no single tool that is used in isolation throughout the process.

Visual representations help designers have a "reflective conversation" with their ideas that in turn allow them to analyze and explore these further [3]. However, a very precise or detailed visualization may cause fixation with the idea and stunt further exploration [4]. Therefore, it is important to identify the effect of different representation mediums on the process of exploration and further define a framework that can help mitigate fixation.

This paper presents findings from the analysis of three case studies of design tasks carried out by undergraduate engineering students from diverse disciplines. It is an exploratory study that helped gain some conclusive learning and insight.

1.1 Aim of Study

Design is a creative problem solving process. In the conceptualization phase of design, multiple ideas need to be created and evaluated to generate concepts. Designers use various externalization tools to record and share their thoughts and ideas. The tools used by designers can have an impact on their design thinking and decision-making.

The aim of the study is to identify the impact of the different mediums of representation used by designers in the process of idea exploration and design thinking.

1.2 Visualization in the Design Process

Visualization is an important part of the design process. Designers need to visualize their own ideas and, with the help of different mediums, convey these ideas to others. An effective visualization plays an important role in decision-making. Stappers and Hennessey mention that 'design solutions emerge from the interaction between the designer and the visualizations' [5]. Bilda and Gero discuss that externalizations of ideas are central to designing. Externalizations represent the development of designs; those have an interactive role to play and area crucial effect in the mechanism of the design activity [6].

Visual design thinking is the essence of the design exploration process and creativity plays an important role in design thinking [2]. Seeing is the experience of sensation and knowledge is the construction of meaningful perception. The media used by designers affects the process of design exploration and design thinking. Certain ideas can only be derived from specific tools and from individual use of media [2]. On the other hand, use of specific media can dictate the design output. Designers use sketches, doodles, quick mock-ups and various CAD tools to help them visualize their own ideas and have an exploratory dialogue.

Sketching plays an extremely important role in the design process. Freehand sketching has always been considered as a core conceptual tool. It allows designers to externalize their thoughts and engage in a dialogue with the idea. The abstract and ambiguous nature of sketches allows designers to make unexpected discoveries and come up with various interpretations and new ideas [7]. 'Despite the importance of sketches in concept building, these are 2D representations of what is hoped to become 3D forms' [8].

Modeling is another tool vastly used by designers for conceptualization. This provides designer extensive tactile feedback and allows them to reflect continuously on the design. In an experiment conducted by Jonson to compare the CAD with sketching and modeling, he found that though the sketching is used as a primary tool, it is always used in combination with CAD or physical modeling [9]. He found the role of sketching less prominent in practice than that advocated in literature [9]. In an experiment conducted by Wojtczuk and Bonnardel, they presented designs made by two group of designers, one using CAD systems and other using manual modeling to a panel of judges; a significant preference for objects designed with a CAD system was noted [7].

Lawson argues that CAD could support designers in exploring ideas and give freedom to visualize their creative imagination [10]. Although, quality of outcomes can be debatable, he agrees that CAD enables designers to produce convincing original designs. Lawson expressed his concerns about design students combining poor designs with impressive and convincing computer presentations. He mentions that 'we live in such a televisual age that any information that looks televisual is automatically considered authoritative' [10]. Wergles and Muhar quote that the realistic visualizations cause a "genuine excitement and anticipation" that can bias the decision makers [11].

Fixation in design ideation is defined as ‘a blind adherence to a set of ideas or concepts’ that limits the exploration and thus the output of conceptual design [12]. Gero mentions that fixation can be of two types; first one in which the designer appears trapped by an existing precedent solution and other is the premature fixation that occurs due to commitment to a particular set of design decisions that the designer does not want to change [4]. A pictorial representation of design solution prior to design session can lead to fixation. Fixation prevents innovation because the designer cannot move to the conceptual space, which is where innovative changes can occur [4]. Sometimes, to decide on the outer form or skeleton size, a lot of internal detailing is done in the initial phases. This leads to premature detailing, and hence reluctance to make changes in the detailed model.

2 Method

The fluidity of the subject being studied has guided the data collection and analysis methods to draw deep and more insightful learning and inferences. The use of qualitative analysis is specifically used towards this purpose.

The three cases reported are part of a course—‘Introduction to Design’ for undergraduate level engineering students from different disciplines. The course focuses on teaching and implementing of the design process and design thinking through case studies and class exercise. The course culminates in an end semester group project where the students are required to generate their own case study and describe their design journey in solving a design problem.

The method of document analysis is used. The study documents the various exploration and representation done by the students to convey their ideas, to gauge the effect of representation modes on the design explorations and idea outcomes.

The study uses an exploratory approach to gain some conclusive learning and insights.

2.1 Description of Research

The project depicted was part of a graded design assignment submission of the course ‘Introduction to Design’. The case studies chosen for this study involved 28 undergraduate engineering students of various streams in their second and third year of study. The groups consisted of 8–10 students from varied streams. The students possessed same proficiency of sketching, and prototyping, but choose the medium of representation to best suit the complexity of the concept. There was a mix of male and female students but that has no implications on the study. The project was carried out in stages over a period of four months, including 3 hours per week of class time.

The design case studies focused on innovative product ideas to address certain space, functional and utility needs of resident students. The cases are:

(i) Space optimization furniture for hostel mess
(ii) Space optimization furniture for hostel rooms
(iii) Space and function optimization of student cycle.

Students were instructed to document and explain their design exploration, as well as articulate the same in a report and a short presentation, for which they would be awarded certain grades to fulfill the credit requirements. The Torrance Creative testing parameters combined with a quality parameter is used to measure the out come. The quality of an idea or concept is judged to the level of relevance of the idea to the need, its usability, technical feasibility and implement-ability [13–15].

2.2 Procedure and Task

The course instructor introduced the participants to the design process and trained them in its implementation through case examples and class exercise. They were guided to identify an area of need under the broad umbrella of space optimization, and explore and generate innovative ideas. They were given free rein to choose any mode of representation to articulate their design outcomes to fulfill the need.

2.3 Data Collection

The study draws its inferences from the documented worksheets and presentations. Students were asked to detail their case study with idea sketches and annotations. They used various forms of representation to craft and communicate their concepts. Figure 1 depicts at a glance the three case studies.

3 Analysis

The work sheets generated by the participants were analyzed and the generated outputs were measured.

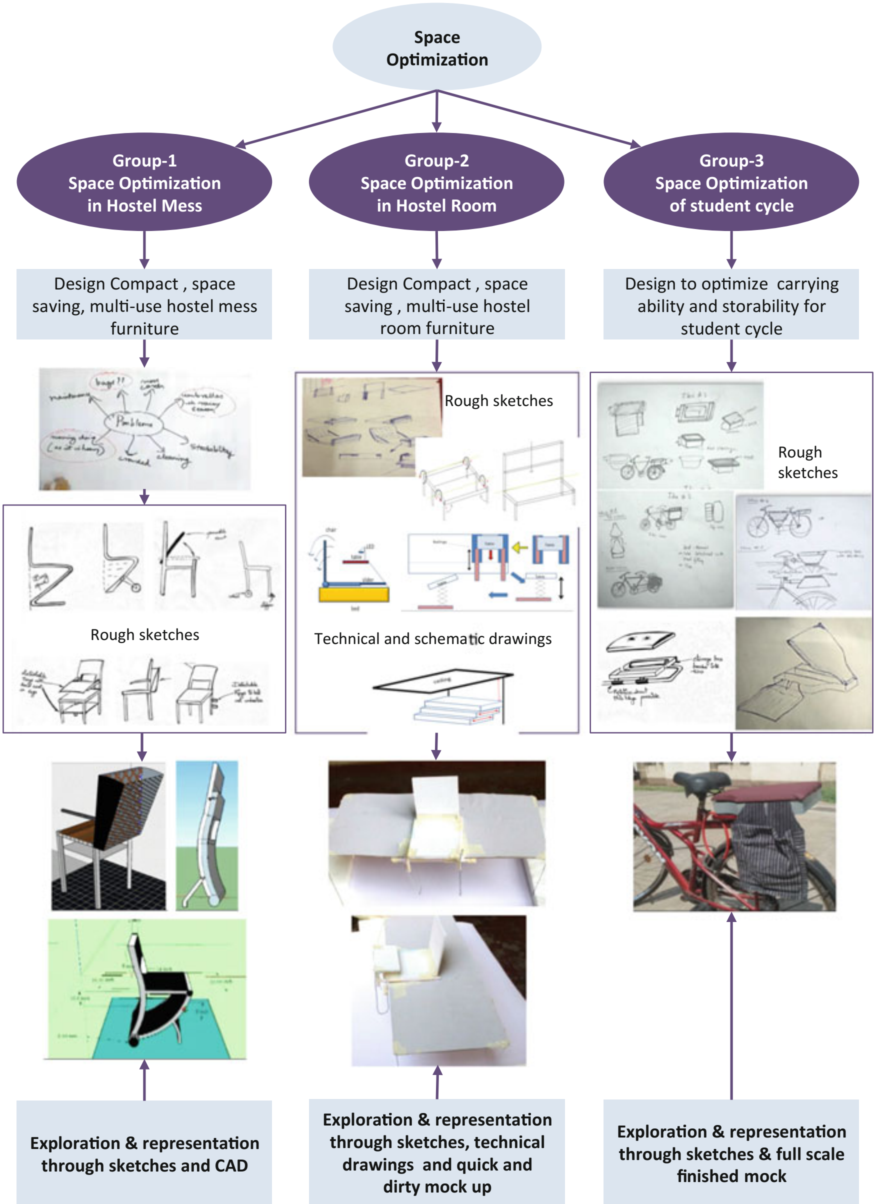


Fig. 1 The designs at a glance

3.1 Criteria of Measure

Measurement is a process of mapping aspects of a domain onto other aspects of a range according to some rule of correspondence. The qualitative assessment was classified into parameters [16].

Base parameters used for evaluation were:

- **Fluency**: Maximum number of ideas/solutions generated in comparison to the others.
  Most number of ideas produced-3; about half of the maximum-2; not many ideas produced-1.
- **Flexibility**: Maximum number of different types of ideas explored and produced.
  Many types of explorations attempted-3; about half of the maximum-2; not many types-1.
- **Originality**: the unusualness of the ideas. This was based on the experience of the judges-their experience as design practitioners and educators.
  Unusual idea-3; not so obvious, yet not unusual-2; obvious idea-1.
- **Elaboration**: the detailing of the ideas, many ideas or details of one idea.
  Maximum ideas on detailing-3; not too many detailing ideas-2; very little detailing ideas-1.
- **Quality**: the relevance of the idea to the need, its usability, technical feasibility and implement ability [13–15].
  High-3; medium-2; ok-1.

The groups started with initial sketches to represent ideas and moved on to various other modes of representation for exploration and idea implementation. The final representations along with the ideas were scored by 3 raters consisting of the course administrators and an external judge. A set of raters was used to measure the idea exploration outcomes, which was notified to the judging panel. They rated the outputs based on the direction of the metrics used.

3.2 Analysis and Findings

The rated scores were tabulated to depict the findings and insights

Group 1: Explored ideas with sketches and elaborated on ideas in a digital computer drawing mode, which was able to provide a realistic view. They displayed high levels of originality and quality in designing an Innovative, multi-functional, stackable mess chair. Ideas were generated for one problem at a time and further clubbed together to form a concept. These concepts were further explored on CAD.

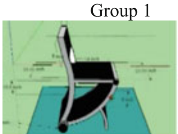
The CAD drawing did not inhibit the exploration of ideas or the representation of the creativity of the idea, rather allowed the next level of exploration and refinement that CAD offered.

Group 2: Explored ideas with sketches and technical drawings and elaborated on ideas with quick and dirty mockups to design a multi-purpose, space optimizing, compact, ergonomic and comfortable hostel bed. Though their representation mode did not have a finished look, they displayed high level of originality and quality like Group 1, as their model allowed interactive display, scope of exploration and experimentation.

Group 3: Explored ideas with sketches but more from the perspective of elaboration. They put a lot of concentration on representing the idea of a compact, functional, utility based cycle accessory that is easy to install and maintain in a finished working proto type mode. This somehow bounded their exploration a bit, which reflected on their originality scores. The focus was more towards the quality factors of usability, technical feasibility and implement ability, which inhibited frequency, and flexibility of ideation to some extent (Table 1).

The findings clearly assess the novelty of ideas and their relation to the representation modes applied. It clearly displays that whatever the mode of representation might be if it is used for furthering exploration it can help in creative output. As long as the mode of representation carries out the idea exploration be it in visual form or in interactive form the creative output will not be inhibited, or the design decision getting skewed. As seen from the output of Group 1 and 2, the representation mode helped the design decision to explore and evolve the ideas further. In the case of Group-3, the representation mode of prototyping did not allow any further development from the initial ideas. From this it can be seen that real-life

Table 1 A comparative table of ratting

	Group 1  				Group 2 				Group 3 			
	R1	R2	R3	Ave	R1	R2	R3	Ave	R1	R2	R3	Ave
Fluency	3	3	3	3	2	3	2	2.3	1	2	1	1.3
Flexibility	3	3	2	2.6	3	2	3	2.6	1	1	1	1
Originality	3	3	3	3	3	3	3	3	2	3	2	2.3
Elaboration	2	2	1	1.7	2	2	3	2.3	3	2	2	2.3
Quality	3	3	3	3	3	3	3	3	3	3	3	3
Comment	High fluency, flexibility, originality and usefulness. There is fair elaboration of ideas				High flexibility, originality and usefulness. There is fair fluency and elaboration of ideas				High usefulness. There is fair elaboration and originality of ideas Less fluency and frequency			

3-2.4 =High   2.3-1.7 =Medium   Below 1.7

representation runs the risk of inhibiting the exploration of ideas and influencing the design decision.

4 Conclusion

Even a roughly finished idea having deep explorative attributes has the potential to generate creative product output. It can be stated that real-life prototyping if avoided in the concept exploration phase can help override biased design decision. Design decisions during idea exploration of new product are not affected by representation techniques. As stated by Nguyen and Zeng, design fixation happens when the designer is heavily attached to a solution and also when designers think they do not have enough time and resource to make changes they will try to stick to the fixated idea [17], which can be seen in the case study-3. Thus to mitigate fixation during idea exploration with any form of representation techniques, certain steps or methods can be devised to promote different levels of exploration within the representation techniques. The only point of concern in rating such ideas is that it requires experienced experts from the field to gauge the creative potential. Further work needs to be carried out to set certain steps of operation to maintain the flow of exploration no matter what the mode of representation might be,as this investigation does not fall in the purview of the existing study.

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A Design Evaluation Framework for Developing Communities

Euan Coutts, Joey Ho and Alex Duffy

Abstract In the field of design within developing communities, a significant need exists to look beyond providing aid, to produce designs that create long term benefits for the community, facilitating empowerment and self-sustainment. Despite a growing range of literature within this field, there are currently no tools, methods or approaches that adequately address this need. A shortcoming that is addressed within this paper by exploring the criteria required within such an undertaking, and proposing an evaluation framework to aid designers. Through an experimental study, the framework was assessed in its potential to aid both the concept generation and concept evaluation process. Results indicate that designers were able to generate more suitable concept solutions, and demonstrated a greater understanding of the long term impacts of the solution on the community through the use of the proposed framework.

Keywords Design for development · Community · Concept evaluation · Concept generation

1 Introduction

Product design has increasingly been highlighted as an important factor in improving quality of life. Many organizations now dedicate time and resources into producing practical solutions to alleviate deprivation within developing communities. However, many projects that seem feasible in theory often fail or worse, hinder the development process they set out to benefit [1].

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In recent years, various different approaches have been created to aid the design process within this field, yet the majority of the literature available on product design has been based on affluent economies. Knowledge on design for developing communities is scarce in comparison, in many instances containing contradictory information and viewpoints [2].

There is a need to investigate existing knowledge within this design field, and to collate and analyse this information. This will allow for a better understanding of the design process required within such projects, and of how to conduct them with a higher chance of success.

To resolve any differences in terminology, this paper firstly proposes a clear definition to the design field. This is followed by an analysis of previously conducted projects and a review of existing approaches, where products are considered as tangible artifacts, which concludes with the identification of three main product categories. A framework for developing products which have a long term positive impact on the user and the community is then derived from a review of literature and past examples of community based projects. The proposed framework is tested in its ability to aid designers in the design process, and the paper concludes with discussion on the results of this experiment.

2 Review of Terminology

In order to characterise the term "developing communities", a review was conducted on various related terminologies within this field. Many existing terms defined groups of people based on economic factors alone. While a low income may be a key characteristic of the communities being considered, research highlights that poverty is more complex than the characterisation of those who are "poor". A study by Nakata and Weidner [2] highlighted the importance of drawing distinctions between those who simply have a low income and those living in poverty, defining poverty as the deprivation of economic, physical, psychosocial and knowledge capabilities or opportunities.

The most well-known form of deprivation is related to economy. Within developing communities, residents can have very little income. This is compounded by low employment rates which characterise low-income communities. The second deprivation is physical. These deprivations include the lack of accessible and affordable healthcare, a lack of healthy, varied diets, and unsuitable living conditions [2]. Psychosocial deprivation relates to the mental health of the overall community. As poverty can lead to uncertainty, stress and anxiety, any long periods of poverty can result in social isolation, depression and low confidence [3]. Finally, knowledge deprivation relates to the lack of education within areas, leading to difficulties in performing basic maths, reading and writing.

Based on this research, a definition of "design for developing communities" (DFDC) is proposed: The development of products for societies with economic, physical, psychosocial and knowledge deprivations.

3 Analysis of Previous Projects

Much of the existing research within this emergent field has been based upon the analysis of past products [4]. Published cases of design within developing communities were reviewed which highlighted conflicting views within literature as to what constitutes a successful product within DFDC projects. Easterly and Easterly [5] argue that products which only benefit the user temporarily, but do not address the roots of the problems cannot be seen as successful product design. A study by Bourguignon and Sundberg [6] found that many forms of development aid do not contribute to long term economic growth, and as such, are not worthwhile uses of resources. This was expended upon by Prazeres [7] who argues that temporary aid is not only useless, but has a detrimental effect on the development of economic markets. These views are reinforced by examples of previous products which tackle the surface-level issues and not the underlying problems, resulting in no lasting positive effect on the community. Throughout this body of work, a long term effect, positive or negative, is considered to be an effect which endures beyond initial or immediate product deployment or use.

In contrast, many argue for an increase in aid for products to help those in need [8]. Contrary to the research highlighted above, many researchers argue that emergency international aid is not only important, but has benefited many communities and have led to positive long term effects on economic growth [9, 10].

With established needs for community development, as well as evidence of instances where aid was necessary, research highlights a place for both of these viewpoints. A review of these papers highlights that the conclusions reached are largely based on the context and the type of project or product being deployed. This suggests that the views are not necessarily conflicting, but are instead views on different product categories.

It is concluded that products developed in a DFDC setting can be broadly classified depending on the function of the product. These categories are:

Product type 1. Products developed to provide solutions to immediate problems.
Product type 2. Products developed to make a profit.
Product type 3. Products which provide long term, positive impacts on the user and the community.

While many products may fall into more than one of these broad classifications, the three product categories could explain why there are so many conflicting and, sometimes contradicting views within this field of design. As each type of product has a different focus and objective, the approaches and opinions on best practice will also differ.

4 Relation of Existing Approaches to the Observed Product Categories

It is clear that DFDC projects can be complex, and have different needs to traditional design projects. As such, a range of tools and approaches have been created specifically to aid the design process within this field. A review was undertaken on various approaches, and were related back to the identified product types outlined above.

Approaches towards Product type 1—"For immediate aid"

The importance of user centred design has been reflected in the numerous approaches which focus on the need to empathise with the end users [11–13]. It can be argued that the user centred design approaches are adequate to create products for immediate aid, as the main aim of these products is to solve a problem users are facing. By utilising the tools available within the approaches, such as co-creation [14] and empathic design [13], a clear understanding of the problems which the users face would be defined.

Approaches towards Product type 2—"For profit"

Business development within developing communities has grown in popularity within recent years [14]. Many of the reviewed approaches deal specifically with how to introduce and create profitable products within a DFDC setting, either as the entire focus, or partially [11, 15–17]. These approaches contain tools such as rapid marker assessment [11] and different marketing strategies [15]. It is clear that this is a highly researched and examined area.

Approaches towards Product type 3—"For enduring impact"

One of the main, and arguably the most important, categories are products which provide lasting positive benefits to the users. The need to look beyond aid to develop products which produce positive lasting effects has been acknowledged within a few of the approaches reviewed, but not in great amounts of detail. Unlike Product types 1 and 2, no approaches analysed provided practical tools on how to create Product Type 3.

Having identified this significant shortcoming, procedural guidelines in the form of a design framework were developed to aid designers in creating and reviewing products specifically to have lasting positive effects.

5 The Framework

In order to create a framework, it was first necessary to review existing literature available on community based products, highlighting any common reasons for failure and success within this design field, as documented in Sect. 3. Any existing recommendations relating to particular approaches previously used and their validity has also been reviewed to supplement this, as documented in Sect. 4. This information allowed for a comprehensive overview of the important criteria required for a product to successfully create positive, lasting effects to a community.

Based upon the reviews in Sects. 3 and 4, a product evaluation framework was created to be utilised during the early design stages. This decision was made as it is during the initial design stages that the largest changes to project direction can take place, and with the most ease.

The proposed framework, displayed in Fig. 1, evaluates concepts against each other based on how well they meet the criteria set, and therefore on how well the product will create positive, lasting effects on the community. The tool generated took the form of an evaluation framework, adapted from Pugh's popular controlled convergence matrix [18]. This format was chosen as it can be assumed that a large range of designers will have experience in using such a framework, and thus are familiar with how to conduct the evaluation.

CATEGORY	CRITERIA		PRODUCT X		PRODUCT Y	
Eliminate concepts which do not tackle the root cause						
		Weighting	Score	Weighted	Score	Weighted
USER NEEDS AND VALUES (please list to the right)	Low cost	1	3	3	4	4
	No reading skills required	1	4	4	5	5
	Safe to use	1	2	2	3	3
COMPATABILITY WITH THE COMMUNITY (please list to the right)	Utilises local materials	1	2	2	1	1
	Job creation	1	3	3	5	5
	Accessibility	1	4	4	3	3
POSITIVE ECONOMIC EFFECTS	IMMEDIATE EFFECTS	1	5	5	2	2
	LASTING EFFECTS	2	3	6	1	2
POSITIVE PHYSICAL EFFECTS	IMMEDIATE EFFECTS	1	4	4	3	3
	LASTING EFFECTS	2	4	8	1	2
POSITIVE PSYCHOSOCIAL EFFECTS	IMMEDIATE EFFECTS	1	2	2	2	2
	LASTING EFFECTS	2	4	8	3	6
POSITIVE KNOWLEDGE EFFECTS	IMMEDIATE EFFECTS	1	5	5	4	4
	LASTING EFFECTS	2	1	2	4	8
TOTAL				58	50	

Fig. 1 Proposed framework-completed example

To complete the framework, six steps are required:

Step 1: Eliminate concepts which do not tackle the root cause.

A distinction should be drawn between products which provide temporary aid in emergency situations, and products which simply mask the effects of bigger, social and economic problems. An analysis of existing community based projects revealed that a major issue was failure to address the underlying issues of the problem, tackling only the symptoms of a much larger problem. This step was included to ensure designers define the root cause of the problem before advancing any further within the process.

Step 2: Fill out the user needs and values.

It became evident that a principle reason for a product failing to achieve lasting positive benefits was due to a lack of user understanding. The reason for this may be due to preconceptions and assumptions the designers make [19], and the frequent discord between what the designers and the users perceive as value [20]. No matter how well a product works, a lack of user understanding will lead to failed products as users will be reluctant to utilise them. Leaving this area blank forces the designer to think about the users' perception of value by filling in the gaps, rather than rely on their own assumptions.

Step 3: Determine criteria for the product to be compatible with the community.

A lack of understanding of the user is also indicative of a lack of understanding of the overall community. Within tools for investigation, Jiang and Kandachar [4], note that local knowledge is imperative when designing for a specific community. Without this, designers may find it difficult to produce products that will be taken care of and implemented within the community. Research highlights that many successful products not only provided solutions to problems, but also built upon local assets, existing markets, and empowered locals [21, 22]. Again, this step ensures the designers identify the necessary requirements to ensure the community is considered thoroughly.

Step 4: Consider how the concepts will tackle the causes of poverty.

It has been argued that, ultimately, for a product to create long term positive changes, it must tackle the causes of poverty [5]. Within this step, perceived lasting effects, determined as projected positive effects by expert judgment, have a weighting of double compared to all the other criteria, due to the significance of this aspect. Even if a great solution is developed, the proposed framework will place emphasis on concepts which produce positive lasting effects over a solution which doesn't.

Step 5: Fill out the matrix, scoring the remaining concepts on how well they satisfy the criteria. Eliminate, refine or adapt concepts based on scoring and repeat.

As with most design evaluation techniques, the process should be iterative. The concepts should be reviewed, eliminated, or refined based on areas it performed weakest, before being evaluated again to allow for further improvement [23]. As these considerations were based on recurring problems with products that have failed to produce the positive effects they set out to achieve, it can be deduced that by encouraging designers to consider these criteria carefully, more successful products will be created.

6 Experiment Design

An experimental study was undertaken involving participants with at least 4 years of design engineering education. The experiment aimed to investigate whether the proposed framework will aid the designers in the process of creating and evaluating concepts that have the biggest positive long term effects on a community. Participants were set a project brief, detailing a design based problem for a developing community. Two groups of 12 participants (12 in a control group, 12 in an experimental group, totaling 24 participants) completed the task: a control group, which was given no explicit guidance on how to conduct the design process, and an experimental group, specifically asked to utilise the proposed framework. Through the experiment, the framework was assessed in its potential to aid both the concept generation and concept evaluation processes.

A project brief was set, framed within a hypothetical scenario in which a charity asks the participant for their help as a designer. It detailed the problem of house fires within slums in a developing community caused by kerosene lamps, which easily spread due to the proximity of the buildings. Information in the form of a paragraph on the community and the users was also given to the participants. The experiment consisted of 3 key tasks. Task 1 related to concept generation, task 2 related to concept evaluation and task 3 was a concluding questionnaire.

7 Experiment Findings—Task One: Concept Generation

The initial task asked the participants to generate a solution to the given brief. As the experimental group had the evaluation framework at hand, the task also investigated whether prior exposure to the terms and definitions used in the proposed framework would affect the designers' ability to produce suitable concepts.

To review how well the participants conducted the concept generation task, an expert was asked to rate each generated concept on a scale of 1–10 based on their suitability to the project brief. The expert is a presiding officer of a charity working with developing communities with 6 years experience, and as such, was deemed well informed to conduct the task. Figures 2 and 3 demonstrate the rating each concept was given by the expert.

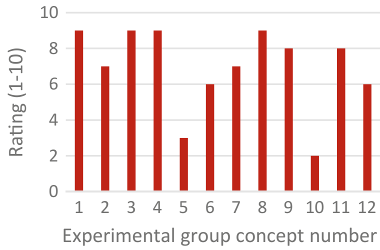


Fig. 2 Task 1 experimental group results

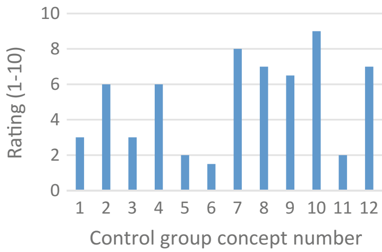


Fig. 3 Task 1 control group results

The results of task 1 highlighted that the experimental group who were given the proposed framework beforehand, produced more suitable concepts than the control group. As a result, the overall mean ranking for the experimental group was 6.91, and 5.08 for the experimental group. The experimental group also displayed more consideration of how the overall community would be impacted by their solution, and also managed to successfully tackle the root cause more frequently.

A T test was also conducted to successfully validate the results, suggesting that the improved performance was a direct result of reading through the proposed framework. This result could be attributed to the fact that the terms found in the framework such as "root cause" and "compatibility", were criteria that the experts were looking for when judging the concepts. It is evident that although the proposed framework was created as an evaluation tool, it still aids design engineers in producing more suitable concepts.

8 Task Two: Concept Evaluation

To test the framework in its ability to aid the concept evaluation process, a list of pre-generated concepts were compiled; all possible solutions to the problem posed. The developing communities' expert was then asked to rank the solutions on their suitability to the brief based on their expertise. The task asked both groups of participants to evaluate the list of pre-generated concepts based on how well they

Fig. 4 Task 2 experimental group results

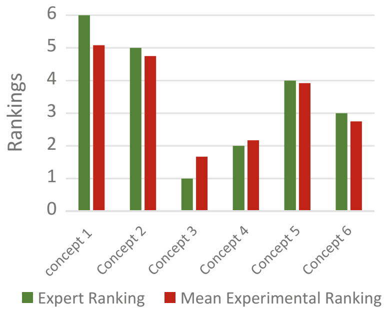
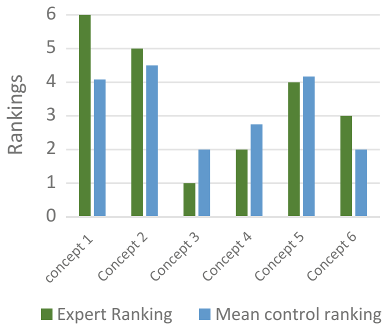


Fig. 5 Task 2 control group results



believed the concepts were suited for the proposed brief, and how well they would produce lasting positive effects within the community. The control group was asked to conduct this task utilising any method that they felt appropriate, while it was requested that the experimental group utilise the proposed framework. This group was also given a background information sheet which explains the steps in the process, as well as definitions and elaboration on the key terms found in the framework. The results were collected, and the mean rankings were compared to the rankings given by the expert, as shown in Figs. 4 and 5.

The results highlight that the mean experimental rankings were closer and more accurately reflected the expert rankings. This suggests that the framework aided the experimental group in evaluating the concepts, as it allowed a bigger majority of participants to rank the concepts correctly.

However, Figs. 4 and 5 highlight that the results from both the control group and the experimental group mean rakings were fairly similar with the expert. A T test was also conducted to validate the results, however the results were not significant. Discussion on why this may be the case is provided in Sect. 10. Although the experimental group performed better, the control group overall were also able to recognise the most suitable concepts and the least suitable concepts successfully, but at a lower accuracy level compared to the experimental group.

9 Task Three: Concluding Questionnaire

The experiment was concluded by asking participants to complete a questionnaire regarding their perceived opinions on the adequateness of their training in completing tasks 1 and 2. This revealed that 75% of the experimental group agreed that the proposed framework aided their undertaking of the task, with the other 25% neither agreeing nor disagreeing. The questionnaire also highlighted that 75% of the control group felt that they would have benefitted from a framework which highlighted key criteria to consider.

10 Discussion and Conclusions

A rigorous study was conducted, and the results highlight that the proposed framework aided the design engineers significantly in their ability to generate suitable concepts which would have lasting effects on the community. Utilising the framework, the designers were also able to recognise the key information required to successfully evaluate concepts more suitable to the community described. While the results for the concept evaluation task did not provide conclusive evidence of the benefits of the framework, there were many reasons why this may have been the case.

The results may be attributed to the small sample size, which led to a non-distributed range of answers. However, the similar results could be attributed to the information given to both groups. To ensure both groups had the same information available, and that the experimental group was adequately equipped to fill in the proposed framework, both groups were given the same background information sheet. As such, all the important information was supplied to the participants in the brief, and within descriptions of the concepts. As well trained design engineers, participants within the control group could have reviewed this information, and highlighted the key considerations without the framework. This suggests that the information collated from the framework was the important variable which would result in the successful evaluation of the concepts. By providing all the information required, both teams were able to effectively emulate the experts' responses.

These results, along with the results of task 3, which reveal that the designers perceived the framework as beneficial within the process, validate the need and potential impact of the proposed framework within the field of design for developing communities.

Future studies should be performed to conduct further field trials of the framework in situ, allowing for a longitudinal study within real design projects. This would allow for the monitoring of the solutions developed, determining what long term effects they have on the community, if any.

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Development and Validation of a Method for Assessment of Novelty and Requirement Satisfaction in Designing

B.S.C. Ranjan and A. Chakrabarti

Abstract The metrics of creativity in design proposed in literature are broadly process—or outcome-based. Process-based metrics assess creativity using characteristics of the design process. Outcome-based metrics assess creativity using characteristics of the outcomes of the design process. However, the current metrics rarely address the issue of how to use the results of creativity assessment during the design process, so that creative effort can be spent at appropriate portions of the process for its betterment. To address this, we propose a method for assessing creativity of a design. It has two metrics: (a) a measure for novelty of a design; and (b) a measure of the degree of requirement satisfaction (DRS) by the design. Creativity in the design is taken as the product of its Novelty and DRS. The method is intended to be utilized throughout the design process, where the overall requirements and solutions proposed in the design and their detailed developments can be connected together and tracked in a linked manner for assessing against the above creativity metrics. The method is explained using an example, and its preliminary evaluation, on a short-term design project with multiple teams solving one problem, is discussed.

Keywords Creativity · Novelty · Degree of requirement satisfaction · Assessment

1 Creativity

The four major aspects of creativity that deserve attention are: the creative process, the creative product, the creative person and the creative situation [1]. These are the commonly agreed, multiple facets of creativity. Creativity is an important perfor-

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mance criterion in designing [2]. Innovation is one of the key factors that positively influence product-success. Management of creativity is essential for effective management of product innovation [3]. Managing creativity requires its assessment. There are many metrics of creativity. To quote Fox [4], "creativity has no meaning except in relation to creative product". Therefore, in this research, the focus is on creativity of the product.

Chakrabarti [5] proposed novelty, purposefulness and resourcefulness as the key indicators of creativity. However, no method or procedure to measure these was proposed. Sarkar and Chakrabarti [6] used novelty and usefulness as the umbrella indicators for creativity. Srinivasan and Chakrabarti [7] proposed measures for novelty and variety as indicators of creativity. A comprehensive survey of creativity metrics has been reported in [8] based on three factors: originality (novel, original, new), appropriateness (appropriate, useful, purposeful, value, meaningful, tenable, satisfying) and various third elements (Unobvious, Adaptive, Leap, Change, Unexpected, Communicated, Transformation, Comparisons, Resourceful). Sarkar and Chakrabrti [9], in their research collected a comprehensive list of the factors influencing creativity.

Shah et al. [10] considered novelty, variety, quality and quantity as four indicators of ideation effectiveness, and proposed methods to assess these. Lopez-Mesa et al. [11] used quantity, novelty, variety and feasibility as factors for evaluating effectiveness of idea-generation methods. Maher and Fisher [12] proposed novelty, value and surprise as indicators of creativity, and developed methods to evaluate each, for assessing products.

Novelty and requirements satisfaction (performance) are two of the factors that keep repeating in metrics of creativity design across researchers. Therefore, this research further focuses on these two factors.

1.1 Novelty

Novelty is the primary characteristic of creativity: "No matter what other positive qualities it might possess, we generally insist as a first step that a product be novel before we are willing to call it creative" [13]. Novelty has been the primary focus in several pieces of research [6, 7, 10–12, 14].

Shah et al. [11] proposed Eq. (1) to assess the overall Novelty for an idea with m functions or attributes and n phases. This equation can be used to compute novelty scores of solutions at various phases of design.

$$M_1 = \sum_{j=1}^{m} f_j \sum_{k=1}^{n} S_{1jk} p_k \tag{1}$$

where f_j is weights assigned according to importance of each function or characteristic, S_{1jk} is the novelty score assigned to each idea against a function or an attribute j at level k. Its value depends on the approach used: a priori or posteriori,

p_k is weight assigned based on the importance of phases' importance, and n is the total number of ideas.

Considering novelty as a major indicator of creativity, Chakrabarti and Khadilkar [14] developed a detailed procedure for measuring novelty. However, the procedure is applicable only at the product level. Sarkar and Chakrabarti [6] used novelty as an indicator of creativity and have developed a method for its assessment. The method is applicable to both products and ideas [15].

Srinivasan and Chakrabarti [7] used novelty and variety as indicators for creativity, and proposed methods for assessing these for products, ideas and concepts. This method rates novelty based the SAPPhIRE model of causality [15]. In this procedure a solution is compared with all the existing solutions to rate its novelty on a scale of 0–7, depending on levels of abstraction at which it is novel. If the solution is new or novel at the action level, it is rated with the highest value of 7. The intermediate values 1–6 are assigned to a solution if it is new or novel respectively at part, organ, effect, phenomena, input, and state-change levels of abstraction. If it is not new at any of these levels, it is assigned a score of 0.

Overall, while a number of metrics have been proposed to assess novelty [6, 7, 10], these apply primarily to a complete solution. Novelty at a system level for a solution is generally not considered as a function of the novelty of its parts and subsystems. Since novelty is a primary factor that indicates creativity, in this research, this factor is used for assessment of creativity.

1.2 Other Factors and Degree of Requirement Satisfaction

Although novelty is a primary factor, many authors [e.g. 4, 6, 8, 13] are of the view that novelty *alone* is not sufficient to assess creativity. To quote Fox [p4, 4], "Somehow the mere oddities must be weeded out". Appropriateness is a crucial criterion along with unusualness [16]. As mentioned before, various other factors such as appropriate, useful, purposeful, meaningful, tenable, satisfying, were also found, from a comprehensive survey in [8, 9], to be used as indicators of creativity.

Sarkar and Chakrabarti [6] proposed creativity as the product of novelty and usefulness. Further, they developed a method for assessing usefulness. Usefulness is defined as the product of level of importance (L), rate of popularity of use (R), frequency of usage (F) and duration of use or duration of benefit per usage (D). However, while R, F and D can be assessed for products that are already in use, it is harder to assess these for ideas or solutions that are still being developed.

Brown [16] also states: "A product must fit the demands of the situation and needs of the creator, and with complex products, the individual parts must form a cohesive whole". This points to the importance of demands, needs and how a product should satisfy it. This particular factor, *satisfaction of requirements*, is

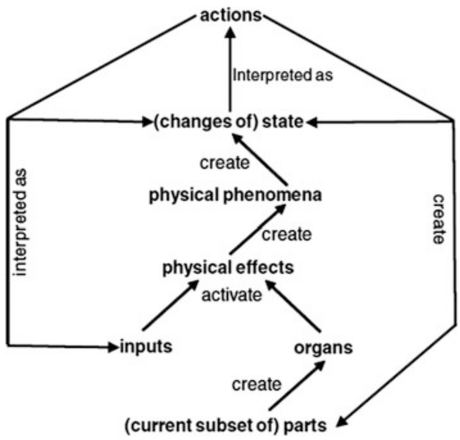

Fig. 1 SAPPhIRE model of causality [15]

repeatedly mentioned in literature in different forms, such as *technical quality* [2], *quality* [10], *fulfilling specified design requirements* [17], etc. However, these references assess requirement satisfaction only at the overall solution level, subjectively, using judges [2, 17]. The three hierarchies of creativity in Sarkar and Chakrabarti [Fig. 1, pg16, 9], show that quite a number of other factors can be linked to novelty and usefulness, while the factor *satisfying requirements*, is just one link below usefulness.

Therefore, in this research, the second factor considered as an indicator of creativity is the Degree of Requirement Satisfaction (DRS). DRS is defined as 'how well a solution satisfies a requirement'. DRS is intended to be a proxy for Usefulness in [6], with the potential of being able to be assessed at idea, concept, and solution levels more easily than Usefulness [6] is in its original form.

2 Research Objectives

The aim is to develop an assessment method that can evaluate the DRS and novelty values at the various system levels of a solution and integrate these to assess the DRS and novelty of the whole solution. Therefore, the objectives of this research are,

1. To develop a method for assessing DRS that can be used to make decisions about ideas, concepts, or solutions during the design process.
2. To develop a method for assessing novelty that can be used to make decisions about ideas, concepts, or solutions, during the design process.
3. To combine these assessments for assessing creativity in order to support allocation of creative effort during the design process.

3 Development of a New Assessment Method for Novelty and Degree of Requirement Satisfaction

In order to support assessment of creativity throughout a design process for any part of the design being developed, what is needed, and is largely missing in current work, is a framework that can take into account the systemic levels within the product and the levels of detail that a product undergoes during its development, since a product is developed by progressive detailing and concreting of its requirements and solutions through multiple levels of abstraction. Extended-Integrated Model of Designing [18], an empirically tested model, is adapted in the proposed method for this purpose; it incorporates three views: *Requirement–Solution*, *Outcomes*, and *System-Environment*.

The *system-environment* view has the following constructs: System, subsystem, elements, relationships and environment. The use of system-environment view in assessing novelty of a product enables the possibility of including novelty at the element level in the novelty of all systemic levels of the product. *Requirements-Solution* view takes into account possible inter-relationships within and between requirements and solutions. Further, a combination of these two views can be used to represent and link systems of requirements and solutions, e.g. by creating a hierarchy of requirements (i.e. a requirements tree), a hierarchy of solutions (a solutions tree), and combining these using various links.

The *outcomes* view consists of the constructs from the SAPPhIRE model of causality [15]: action, state-change, input, physical phenomenon, physical effect, organs and parts. Using this view, Srinivasan and Chakrabarti [7] developed a novelty assessment metric for ideas and solutions (see Sec 1.1). This metric is incorporated in the method for assessment of novelty proposed in this paper. The proposed method is explained using an illustrative example, see Sects. 3.1 and 3.2. The first two steps of the method, developing a combined requirements–solutions tree and identifying system levels, are common to assessments of both DRS and novelty, and are explained only once below.

Step 1 Build requirements-solutions tree to provide clarity of requirement-solution pairs: The first step in assessing novelty and DRS is to develop a combined requirements-solutions tree. This involves the following: development of the requirements tree, the solution tree, and combining these. Figure 2 shows the development of combined requirements-solutions tree with the example of "*Transmit motion-Gear drive*". For the *transmit motion* requirement, possible solutions are *gear*, *rope*, *belt* or *chain drive*. However, *Gear drive* is used when requirement set also includes *between parallel shaft*, *short distance* and particularly *high efficiency*. This makes explicit the relationships among the (sub-) requirements and the (sub-) solutions, which helps to understand as to how a sub-solution contributes to a given requirement, a requirement at a higher level, or the overall set of requirements. The idea of creating a combined requirements-solution tree is similar to creating a balance sheet in accounting. The combined tree provides a representation from which all the requirement-solution pairs present in the design can be identified.

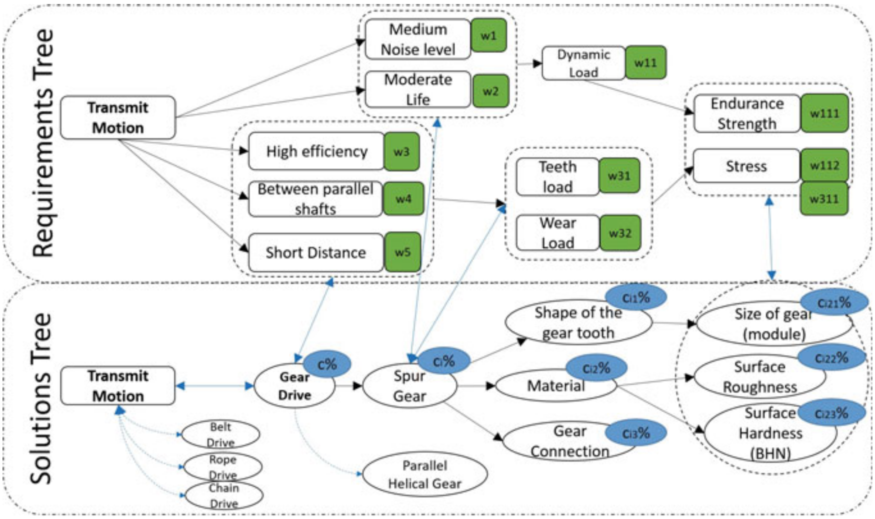

Fig. 2 Combined requirements-solution tree

In Fig. 2, box, green box, dotted box, ovals, blue ovals and dotted ovals represent, respectively, requirements, weight of requirements, systemic boundaries of requirements, solutions, percentage requirement satisfaction value of solutions, and systemic boundaries of solutions. A one-sided arrow represents a hierarchy of requirements and hierarchy of solutions. A double-sided arrow represents a relation between a (set of) requirement(s) and a solution. Dotted arrows represent possible solutions at their respective levels.

Step 2: Identify system levels: The second step is to identify individual requirement-solution pairs, individual elements (group of requirement-solution pairs forming each element), subsystems (group of elements and relationships forming each subsystem), and the system (i.e. group of sub-systems forming the overall system i.e. product).

3.1 Assessment Method for Degree of Requirement Satisfaction

Step 3 Assign weights to requirements: Once a requirements tree is developed, each requirement is assigned a weight w_i based on its importance relative to other requirements at that level. The constraint used in assigning weights is $\sum wi = 1$ at each level of the requirements tree. This is to ensure simplicity in weighting, and to ensure that the overall DRS takes the value of 1 or 0 respectively when all requirements are fully satisfied or not satisfied at all.

For example, if R_1 (with w_1) and R_2 (with w_2) are sub-requirements of the overall requirement R (with w = 1), then $w = (w_1 + w_2) = 1$, e.g. for $w_1 = 0.3$, $w_2 = 0.7$. At the next requirement level, if R_{11} and R_{12} are sub-requirements of R_1, then $w_1 = 0.3$ is converted to $(w_{11} + w_{12}) = 1$, i.e., w_{11} and w_{12} are again rated between 0 and 1 (i.e. 0–100%), say 0.6 and 0.4. Let us assume that R_{21} is the only sub-requirement of R_2. When assessing weights back towards $w, w_{11} = 0.4$, $w_{12} = 0.6$ will be multiplied with $w_1 = 0.3$ ➔ total weight at highest level $w = w_1(w_{11} + w_{12}) + w_2(w_{21}) = (0.3(0.4 + 0.6) + 0.7(1)) = 1$. This ensures that the summation of weightage of all requirements will be 1 which is equal to overall requirement/s. The assignment is similar to that for the Objectives Tree method [19].

Step 4 Find the Level of Importance (LoI) of each requirement-solution pair: The assessor then has to assign the level of importance (LoI, see [6]), i.e. how important the requirement-solution pair is, on a scale of 0–5 as in Table 1. This takes into account the overall importance of the product category to which the requirement tree belongs. In [6], usefulness assessment used the LoI values in Table 1. Further, the usefulness assessment were validated by comparison of assessments to alternative products by experienced designers and hence the LoI values are indirectly validated.

Step 5 Assign percentage requirement satisfaction for each solution: Using a requirement-solution pair in the combined requirements-solutions tree, it is assessed as to the how well the solution at ijk level satisfies the requirement, with a percentage requirement satisfaction value (c_{ijk}) between 0 and 100%. This can be assigned either in case of existing designs, using the information on the existing solutions and their performance or in case of new designs, by providing the performance criteria (numerically if possible) for the solution and how well the solution realizes that criteria. Now, the DRS of the requirement-solution pair at the

Table 1 Level of importance of different products (from Sarkar and Chakrabarti [6]

Code	Points in scale of 5	LoI	Type of importance	Examples
A	5 (> 4.0–5.0)	Extremely high	Lifesaving drugs, life support systems	Oxygen cylinder, pace makers
B	4 (> 3.0–4.0)	Very high	Compulsory daily activities	Taking food, using restroom
C	3 (> 2.0–3.0)	High	Shelter, social interaction	Pen, belt, clothes, housing, spectacles, shoes
D	2 (> 1.0–2.0)	Medium	Machines for daily needs	Cleaning machine, vacuum cleaner, water pump, water heaters
E	1 (> 0.0–1.0)	Low	Entertainment systems, recreation systems	Computer games, bowling, go-carting

ijk level, DRS_{rs} is assessed using Eq. 2. Here w_{ijk}, w_{ij}, w_i are the weights of the ijk pair, ij pair and i pair.

$$DRS_{rs\,ijk} = \left(c_{ijk}/100\right) * \left(w_{ijk} * w_{ij} * w_i\right) * LoI \tag{2}$$

Step 6 Calculate overall degree of requirement satisfaction: The overall DRS of the solution can be assessed using Eq. 3 below.

$$DRS = \sum DRS_{rs\,ijk} \tag{3}$$

When some requirements are not addressed or yet to be addressed in the set of requirements considered by designers, then to calculate the DRS value the corresponding c_{ijk} values (individual solutions requirement satisfaction level) will be considered as zero.

3.2 Assessment Method for Novelty

Step 3 Assign Novelty score to each requirement-solution pair (N_{rs1}, N_{rs2}) using metrics from [7]: Novelty assessment is carried out at the lowest possible level of abstraction to understand what is novel at this level. The assessment is carried out using the novelty metric developed in [7] based on SAPPhIRE model of causality (Sect. 1.1). It has been found that the correlation between values obtained for novelty from Shah et al. [10] method and scores from Experienced designer's is very low [6]. Further, in [10] the novelty is measured in terms of unusualness which might be different from one person to other. Each requirement-solution pair is compared against all existing requirement-solution pairs, to assign novelty scores to each requirement-solution pair. This novelty score, as discussed in Sec 1.1, ranges from 0–7, 7 being the highest.

Step 4 Combine the above scores to assess Novelty of an element (N_{el}): Novelty scores of all requirement-solution pairs forming an element are summed up. To keep the range of the novelty score of the element within 0–7, the sum obtained above is divided by the number of pairs forming the element, see Eq. (4).

$$N_{e1} = (N_{rs1} + N_{rS2} + \ldots.. + N_{rsn})/(n_{e1}) \tag{4}$$

Step 5 Calculate the Novelty of the subsystems (NSS): The novelty scores of all the elements (N_{el1}, N_{el2},…), relationships (N_{Rel1}, N_{Rel2},…), and subsystems (N_{SS1}, N_{SS2},…, if other subsystems are present within a subsystem), forming the subsystem are added together to obtain the summation. This summation is divided by the number of elements, relationships and subsystems (n_{SS}) within that subsystem, to normalize the range of the novelty score of a subsystem within 0–7, see Eq. (5).

$$N_{SS} = (N_{el1} + N_{el2} + \ldots\ldots + N_{SS1} + N_{SS2\ldots\ldots} + N_{Rel1} + N_{Rel2+\ldots\ldots})/(n_{SS}) \quad (5)$$

Step 6 Calculate the Novelty of the system: The novelty scores of the subsystems are multiplied with the number of elements and relationships in them, before adding them together. This is to take into account cases such as those where a single element is part of multiple subsystems, otherwise the novelty value that element will be counted multiple times which is incorrect. To keep the novelty of the system in the range 0–7, this sum is divided with the total number of elements and relationships forming the system (n_S), see Eq. 6. Novelty of the system is.

$$N = (n_{SS1}N_{SS1} + n_{SS2}N_{SS2} + \ldots + n_{Rel1}N_{Rel1} + \ldots)/(n_S) \quad (6)$$

This novelty value of the element, subsystem or system can be normalized to the range 0–1 by dividing it by the maximum value of novelty possible which is 7 to get normalized novelty of the requirements-solution pair (nN_{rs}), element (nN_{el}), subsystem (nN_{SS}) and system (nN_S).

Creativity Score is taken as the product of the novelty and DRS scores, i.e., DRS_{rs} and N_{rs} (or DRS_{rs} and nN_{rs}).

4 Evaluation of Proposed Assessment Method: Case Studies

The proposed method for assessing novelty and DRS is applied on the outcomes of the design sessions from a workshop on “Product Design and 3D-Printing” that ran for 12 days. 32 student participants, divided into 8 teams (T1, T2, T3, T4, T5, T6, T7, and T8), were mentored by the first author. Participants were third or final year Bachelors students in Mechanical or Civil Engineering. All participants were mentored for the first six days on product design and design methods, but were not informed about the proposed method of assessment. On days 9–12, problem P1

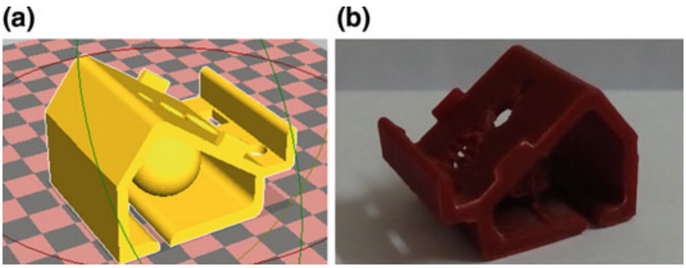

Fig. 3 3D CAD model and 3D printed model from team T1 solving P1 (T1-P1)

(to ‘Design and develop a mobile stand’) was given. The outcomes collected from design sessions were requirements lists, ideas, conceptual solutions, detail drawings as CAD models, and scaled down 3D printed models (to save time of printing), see Fig. 3a, b.

4.1 Results and Discussion

The final solutions—3D CAD models and 3D printed models from each design session were analyzed against the corresponding requirements list generated in that design session. Table 1 shows the requirements and solutions paired together at the lowest possible levels, and the results from applying the proposed method to assess the following for one final solution for one design session: (a) PRS_{rs}—PRS of a requirement solution pair, (b) DRS_{rs}—Degree of Requirement Satisfaction for the pair, (c) N_{rs}—Novelty of the pair, (d) nN_{rs}—normalized Novelty of the pair, (e) C—Creativity and (f) nC—normalized Creativity for the pair. Further application of the proposed method to each of the design sessions confirmed that the method could be used to obtain DRS, novelty and creativity scores in practical cases where a variety of solutions are developed from various requirements lists (with different sets of requirements in each design session) to final prototype (different solutions). Table 2 and Fig. 4a, b illustrate that it is possible to use the proposed method to evaluate DRS, novelty and creativity of solutions against the corresponding requirements.

In Table 2 and Fig. 4a, it can be seen that the design team chose 3 requirements (first requirement has two parts of equal importance) and developed a solution to all the requirements. Problem brief given was for an artefact of Category D (Table 1) and hence its LoI is (2/5). Now, the collective DRS score 0.336 which is 84% of the maximum value that can be achieved (which is 0.4 = 1 * 2/5). This is achieved by variously satisfying four requirements RS1–4, among which RS3 fares the worst, 0.084. The designer therefore can now be informed that he/she needs to focus on the requirement-solution pair RS3 in order to achieve a higher DRS score.

Similarly, novelty values N_{rs1}, N_{rs2}, and N_{rs4} are 1, as designer focused only on the part level of abstraction. However, novelty N_{rs3} is zero as the designer did not propose a new solution. Collectively, the overall novelty score is close to zero. The designer can be informed as to where creative effort should be focused and how, by explaining to the designer where he/she needs to focus for achieving higher novelty.

It can be seen in Table 1 as to how the creativity score is affected by small variations in weights, PRS values and hence DRS & creativity scores: see RS1 ($w_i = 0.25$, PRS = 0.9, $N_{rs} = 1$ and C = 0.225) and RS4 ($w_i = 0.2$, PRS = 0.9, $N_{rs} = 1$ and C = 0.18). In the case of RS3, since novelty value is zero, creativity is also zero. Thus, it can be observed that in this method, the DRS and novelty scores are calculated for the lowest level of requirement-solution pairs; these values are

Table 2 Calculations for the design session T1-P1

Requirement	Solution		W_i	C_{ijk}	PRS_{rs}	DRS_{rs}	N_{rs}	nN_{rs}	C	nC
To hold or support mobile	Support to platform	RS1	0.25	0.9	0.225	0.09	1	0.1429	0.225	0.0129
	Platform and sidestops	RS2	0.25	0.9	0.21	0.09	1	0.1429	0.225	0.0129
Withstand mobile weight	Provide enough material	RS3	0.3	0.7	0.21	0.084	0	0	0	0
Provide charging point	Circular and rectangular gaps	RS4	0.2	0.9	0.18	0.072	1	0.1429	0.18	0.0103
Overall scores					0.84	0.336	0.1071	0.0153	0.09	0.0051

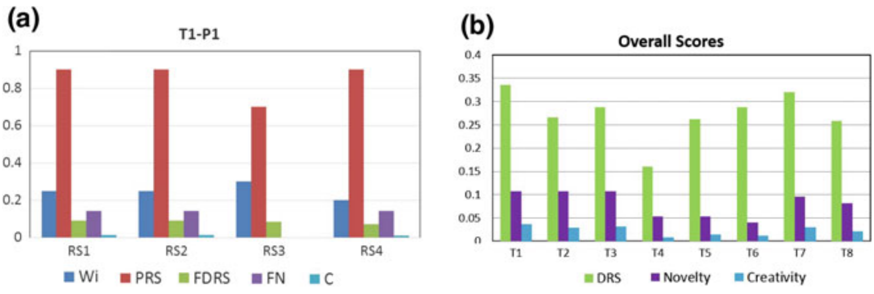

Fig. 4 Individual team's scores of DRS, novelty and creativity for each R-S pair and overall scores of DRS, novelty and creativity for each team

then integrated such that any variation at the lowest level is reflected in the overall scores. Therefore, using Fig. 4a, b, it is possible to do the following:

(1) Compare how individual PRS (c_{ijk}) values affected the overall DRS score.
(2) Compare how individual novelty scores affected the system level novelty score.
(3) Compare how individual DRS and novelty scores affect system level creativity scores.
(4) Illustrate seamless integration of individual DRS and novelty scores of requirement-solution pairs into system level DRS and novelty scores.

The graphs (Fig. 4a, b) are not for comparing the results of DRS, novelty and creativity across different teams (since each team used a different list of requirements), but for self-inspection by each team. Thus, the results in graphs can be used to understand how creative effort of a design team is distributed in the development of the product. Hence, this assessment could help in identifying where the designers should focus their effort to achieve better results in terms of novelty, DRS and hence creativity.

The limitation of the results are that the designs did not involve complex products and overall time taken for product design and development was short, which may have affected the design process. Future work will address both these issues by using the proposed assessment methods in long-term projects involving development of complex products. Another limitation is that the DRS, novelty and creativity scores from the proposed method are not compared against some benchmarks, e.g. expert judges, to check how much the results correlate with the scores from expert judges.

5 Summary, Conclusions and Future Work

In this paper, a method for assessing, novelty, DRS and creativity is proposed. The method is explained with an illustrative example. Further, an initial evaluation of the method is carried out by using it to assess design sessions, where 8 teams separately solved the same design problem. It was found possible to apply the proposed method to the design sessions' outcomes. The results of this assessment further indicate the possibilities of using the proposed method to understand the distribution of creative effort of designers in a design process. It might be possible to use the method as a guiding tool for designers during a design process to help achieve more creative results.

In future, the proposed method should be evaluated by using it to assess long-term design projects. Further, the method needs to be developed into a tool that could be used by practicing designers in their product design and development processes.

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Vastu-Purusha Mandala and Web Page Design: Comparison of Tradition and Modernity

Anshuman Sharma

Abstract Web page design is an important aspect that web and graphic designers learn and master. With changes in form factors and web design trends, web design concepts and considerations are also changing. Mobile first is the new paradigm which is being followed. Various tools like eye tracking have helped designers to understand how users looks at a web page and how content should be displayed in browsers for increased customer stickiness. Usability and eye tracking studies have shown that most users browse a web page from top left and end at bottom right corner of the page. But these are not the only principles that the designers should be aware of. An old Indian concept called "Vastu-Purusha Mandala" has similar features and considerations. Vastu-Purusha Mandala is a pictorial representation of directional principles for construction of buildings and cities. This concept has similar considerations based on philosophy, mythology and climatic considerations of the Indian sub-continent. Ancient cities like Jaipur in India are based on the concept of Vastu-Purusha Mandala. This paper looks at a similarities and differences between elements and principles of web page design and Vastu-Purusha Mandala and identify areas of similarities and dis-similarities for location and relationship of important elements. Additional space design principles and focus areas can be deduced from an old concept which may enhance the perspective of how a web designer looks at design for web. This paper will establish that whether it is space design or web design, user centricity helps plan and design in context for the end customer.

Keywords Human computer interaction · User experience design · Web page design · Website design · Rule of thirds · Vastu shastra · Vaastu purusha mandala · Design principles · Indian town and city planning · Indian mythology · Indian house and site design · Space design

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1 Introduction

In this digital age, wearable devices are taking over from the traditional desktop client based internet experience. The pace of information technology is changing fast. How we use internet has drastically changed over the past 10 years [1]. User experience is driven by technology and channels like mobiles. But still, the age old desktop and laptop based experience is holding good. User and customers prefer applications and software which are intuitive, creative and easy to use.

Web page design is an integral part of the application design and designers need good understanding of web page design principles to address the requirements of multiple form factors. Designers keep looking for inspiration to fields other than design to get customer insights and user preferences. This helps validate certain assumptions the designers may have made about the target audience.

Similar design principles were followed in ancient Indian traditions of house/site layout and design. It will be interesting to compare the ancient site/town planning principles with modern digital principles of web page design and arrive at a conclusion if the ancient design and layout principles still hold good when compared to new age digital design principles.

1.1 Objective

The objective of this paper is to compare age old Indian principles of site and house design—Vastu Purusha Mandala with modern principle of web page design and infer if there are similar principles applicable to both web page design and design of house/site.

1.2 Scope and Methodology

The scope of this paper will be to study and compare:

- Principles of digital design like web page design
- Principles of ancient Indian house/site design—Vaastu Purusha Mandala
- Compare the elements and areas of importance as per the Mandalas and Rule of thirds, the Modulor and grid based design

The methodology followed (Fig. 1) will include the following three main steps:

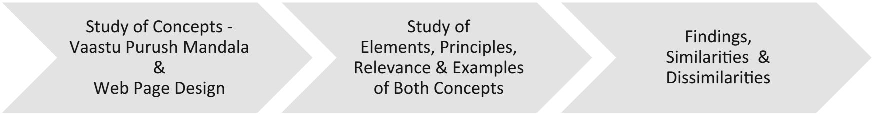


Fig. 1 Methodology

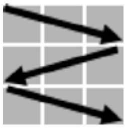
2 Web Page Design

Websites and applications are the backbone of digital age. With evolution of different form factors, the principles of web page design and the use of grids is also undergoing change. But the traditional web page design principles are still relevant.

2.1 *Web Page Layout and Design*

Page layout is where information design, interface design and navigation design come together to form a unified, cohesive skeleton. The conceptual layout or skeleton is also known as wireframe and helps in layout of web page elements based on a grid system.

The grid [2] is used to layout web page elements so that there is consistency across all the pages and the users get a consistent visual and aesthetic experience. The elements on a web page are arranged so that it directs a user's eye movement for smoother navigation and browsing experience [3]. Eye tracking is often used to evaluate the page layout. Proper page hierarchy directs users to the most relevant information and unifies disparate elements into a cohesive whole [4].

 Eye tracking design principle help in layout of page elements in a site. The objective is to guide the user's eye to start from top-left to bottom-right of the web page. If a designer is not able to achieve this desired smooth eye movement, multiple layouts and placement need to be created and tested to achieve the desired result. Web page design uses the eye flow direction to define the location of elements on a web page. Eye tracking test using eye tracking tool helps to validate if the elements have been correctly placed in the web page Fig. 2.

2.2 *The Golden Ratio*

The Golden Ratio is also known as the divine proportion. It is a ratio which used in many ancient Roman and Greek buildings. The basic method to arrive at Golden

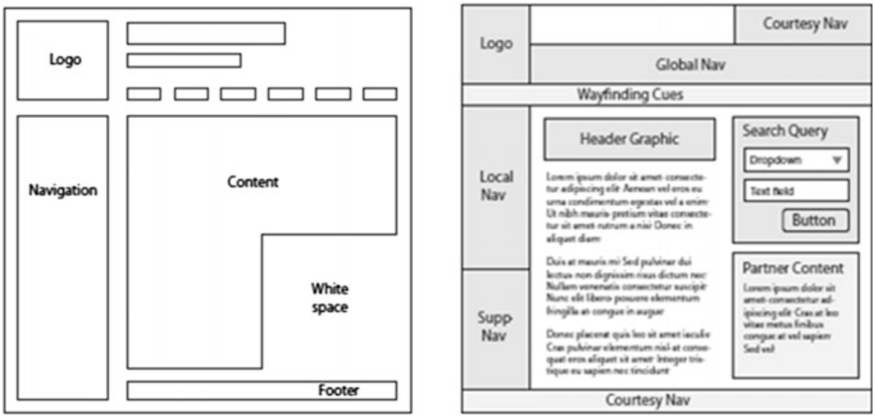


Fig. 2 Sample web page design layouts [5]

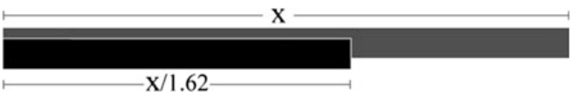


Fig. 3 Process to derive golden ratio

Ratio [3] is represented in Fig. 3. A line can be bisected using the golden ratio by dividing its length by 1.62. This number is usually represented as Φ (pronounced as fi or phi).

2.3 *Rule of Thirds*

A simplified version of the golden ratio is known as the “rule of thirds.” As explained in Sect. 2.2, The Golden Ratio or the rule of thirds can be achieved by bisecting a line into two sections, one of which is approximately twice the size of the other. This is done by designers and architects to avoid lengthy calculations and arrive at a simplified way of following the golden ratio.

Dividing a web page or a site into a grid of thirds is an easy method to achieve the divine proportion. The rule of thirds is the basis of grid based layout. With introduction of mobility and wearable devices, the grid has undergone evolution to cater to multiple form factors.

The classic drawing of the Vitruvian Man by Leonardo da Vinci establishes the basic symmetry of the square. Architect Le Corbusier was concerned with architectural form and proportions. He called his system ‘The Modulor’ (Fig. 4) and built it around three main points of anatomy—the top of the head, the solar plexus, and the tip of the raised hand [3].

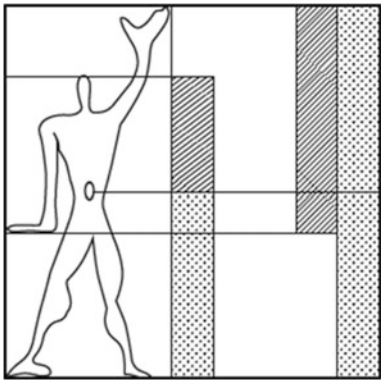


Fig. 4 The modulor [3]

2.4 Principles of Web Page Design

A designer can select any structure for a web page layout, but balancing the structure and relationship of menu and individual content pages or connecting graphics with content on a page is most important. The goal is to build a hierarchy of menus and pages that feels natural to the user and doesn't interfere with their use of the web site or mislead them [6].

Usability, purpose and aesthetics form three pillar of website design. The following are a few traditional visual design principles of which are followed for web page design [3]:

- Balance
- Proportion
- Rhythm
- Unity
- Contrast [2]

Users always see one complete page at a time, so dividing the space is an important factor in arranging the contents (text, headlines, pictures, logos, buttons, etc.) that need to go on a page.

3 Vastu-Purusha Mandala

Roughly translated, Vastu means land to live on and has reference to harmony and balance of man with nature and Shastra refers to treatise. Vastu Shastra teaches us on how we can lay out our house design so that we as human beings can get the maximum benefits of the natural forces given-off by nature. Basically, this system deals with the five elements in Indian Mythology namely, prithvi (earth), jal (water), tej (fire), vaayu (air) and aakaash (sky or ether) which are believed to be sources of natural power [7].

3.1 What Is Vastu Purusha Mandala?

The Vastu-Purusha-Mandala represents the manifest form of the Cosmic being inside a square. The square is the mark of order, the finality to the expanding life. Vastu the manifest, Purusha the Cosmic Being and the Mandala the polygon [8]. The spiritual and cosmic concepts were important to be understood in order to build temples and places of worship (Fig. 5).

Vastu Purusha denotes the emphasis of an area by resting his head in the direction of north-east or north-west which is balanced thinking and his lower-body facing the south-west direction that signifies strength and stability. In the center is his navel, which depicts cosmic awareness and his hand facing towards north-west and south-east depicting energy and movement [7] (Fig. 6).

Vastu defines thirty-two diagrams suitable for all types of sites. The diagrams with its squares are referenced as Mandala or commonly known as Pada [10]. These principles are used for designing building, sites, temples, villages and cities. These principles define the layout of elements. 3D building design concepts are not relevant in this study and are not included in this study.

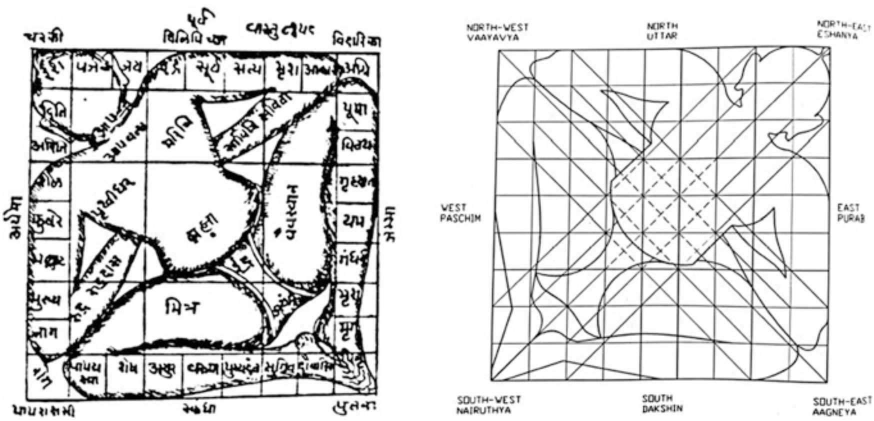


Fig. 5 Vastu Purusha mandala [9]

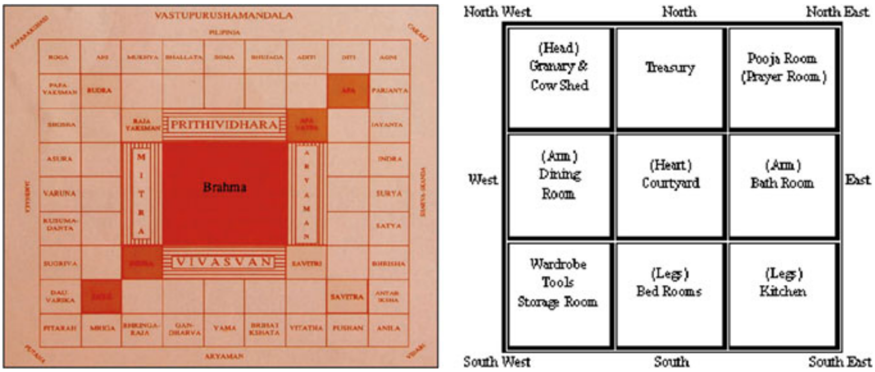


Fig. 6 Disposition of different rooms in a house as per Vastu Purusha mandala [9]

3.2 Examples of Vastu Purusha Mandala Based Site/Town Planning

Concepts of Vaastu Purusha Mandala are universally applicable to space design, but it was looked more from designing houses and allied facilities. There are several examples where towns and cities were also designed on this concept.

Jaipur in North India is an example of first planned cities in ancient India which is based on the principles of Vastu Purusha Mandala [11]. The city is still vibrant and is the capital of Indian state of Rajasthan. The city is built around the contours of the site and makes good use of topography. The king's castle and the shopping center is at the heart of the city with housing towards the south east [Fig. 7]. The castle and the housing around it was so well designed that for centuries the castle was invincible. The roads are straight with perpendicular intersections.

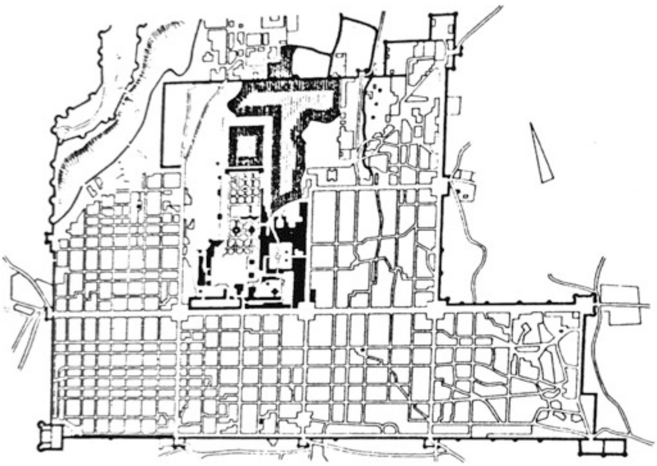


Fig. 7 Plan of city of Jaipur [11]

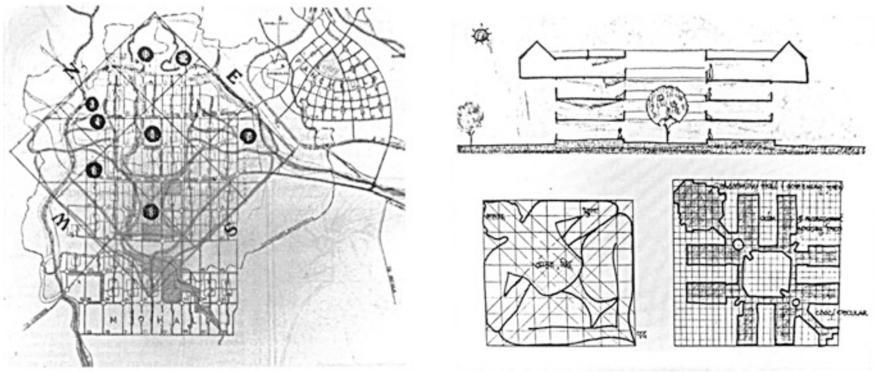


Fig. 8 Plan of Chandigarh [11]

Chandigarh, a new city in North India, planned and designed by Le Corbusier in the 1960s also uses principles of Vastu Purusha Mandala. Chandigarh serves as the capital of two Indian states of Punjab and Haryana.

The Secretariat or the Capital Complex is located at the north west of the city and is the head of the city (Fig. 8). Sector-17, which is the central business district (CBD) is located at the heart of the city. Both arms are represented by Educational institutes on one side (north) and the industrial sites on the other (south-east). Housing sectors are located towards the south which represent the legs (south-west and west). Some of the main governmental buildings are also based on the concepts of vastu purusha mandala (Fig. 8).

4 Method and Findings

Comparison of elements and principles of web page design and Vaastu Purusha mandala can point to different directions of digital design versus ancient housing and town planning principles. This comparison will result in similarities and dissimilarities of both concepts where the functional elements are to be laid out for the user (human).

4.1 Comparison of Concepts—Web Page Design and Vastu Purusha Mandala

Principles and elements of web page design and Vastu Purusha mandala have been explored and understood. Also an effort has been made to ascertain the relevance of these concepts as well.

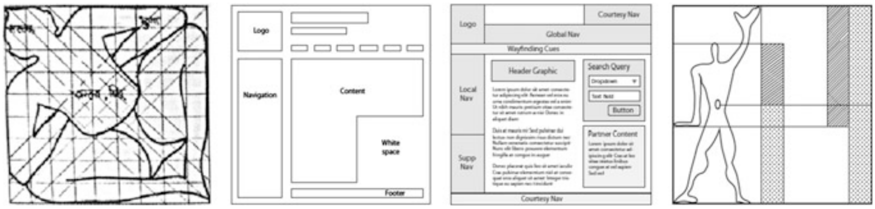


Fig. 9 Comparative representation of Vaastu Purusha Mandala with web page design and "the modulor" [3, 5, 11]

The following concept will be compared for similarities and dissimilarities [Fig. 9]:

- Elements of web page design
- Rule of thirds (golden ratio)
- The concept of grid based on rule of thirds
- Vastu Purusha Mandala
  - human figure in nine Mandalas
  - directional location of elements
- The Modulor

These concepts a have lot in common and have universal application and relevance. Some of aspects compared are:

- Relevance
- Universal applicability
- Design principles and thumb rules
- Context based solution
- Use of environmental/channel factors

4.2 Process of Super-Imposition of Concepts

Based on the parameters and concepts for comparison identified in Sect. 4.1, graphical superimposition of multiple concepts was undertaken. This method helped to compare parameters and relevance of the concepts from multiple dimensions. The super-imposition also helped in visual authentication of the concepts and establish that the core concepts of user/site specific solution is common to all and has universal applicability [Fig. 10]. For example, the heart is where the most important elements of house/site or a web page should be placed.

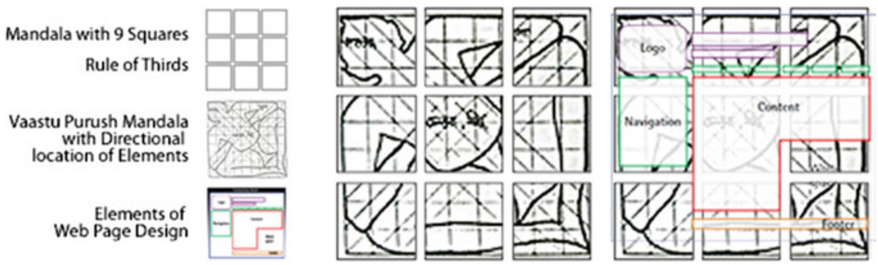


Fig. 10 Comparative superimposition of concepts of Vaastu Purusha Mandala with web page design concepts

4.3 *Results of Concept Comparison*

Figure 11 represents a detailed comparison of the concepts and parameters identified in Sect. 4.1 and the process followed in Sect. 4.2.

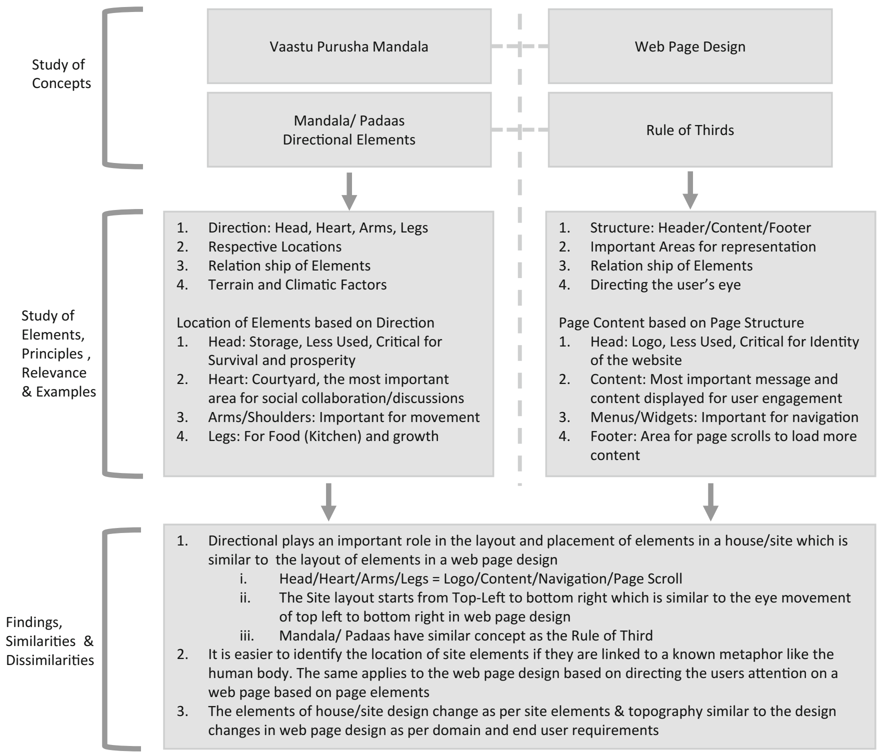


Fig. 11 Comparative analysis of concepts of Vaastu Purusha Mandala with web page design

5 Conclusion and Next Steps

The paper looked at some similar design concepts like web page design, golden ratio and Vastu Purusha mandala. These concepts were compared on multiple parameters and relevance. The findings of comparative analysis are very interesting. Any concept be it for digital design or for housing or site design has universal application when the environmental and user specific requirements are taken into consideration.

Vastu purusha mandala also has religious and spiritual significance, but it has universal application and perfectly compares to the modern digital design principles. This research confirms that web page design, the golden ration or rule of thirds, the Modulor, the concept of Mandalas and vastu purusha mandala have common principles and thumb rules. These concepts have universal applicability and focus on adapting to the end user or the site/land features.

The next step will be to study concepts from other regions and cultures and arrive a common theme of parameters and principles.

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Part III
Design Lexicon, Taxonomy, Ontology

Review and Classification of Knowledge in Engineering Design

Cristina Carro Saavedra, Teresa Serrano Villodres and Udo Lindemann

Abstract Understanding what types of knowledge need to be managed is essential for researchers and practitioners in order to implement knowledge management within the engineering design process. However, obtaining a fast overview from literature of the types of knowledge to consider is not an easy task. In order to identify the types of knowledge in engineering design, we conducted a literature review searching for classifications of design knowledge. We analysed the types of knowledge from the literature and summarized them in a taxonomy to classify design knowledge. The taxonomy can be used as a theoretical base for researchers and practitioners dealing with knowledge management in engineering design, in order to support the understanding of the type of knowledge to consider for their purposes. It can be also used to classify the knowledge of a company in order to match it with the situations during the design process that each of the identified knowledge types can support.

Keywords Knowledge · Knowledge types · Literature review

1 Introduction

Design knowledge is defined by [1] as "knowledge that can be used to produce designs". Different types of design knowledge are needed for product design. Knowledge management is the discipline that aims at capturing, distributing and effectively using knowledge in organizations [2]. The main purpose of managing knowledge is not to become more knowledgeable, but to increase the awareness of

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possible solutions to problems that already exist and how to access those [3]. Knowledge management in engineering design is beneficial because it avoids “reinventing the wheel” and repeating past mistakes [4].

Understanding what types of knowledge need to be managed is essential for researchers and practitioners in order to implement knowledge management within the engineering design process. However, obtaining a fast overview from literature of the existing knowledge types is not an easy task. Some authors such as [5] classify design knowledge in market, human, procedural and technology knowledge. Others, classify knowledge in engineering design as technical know-how, functional and structural rules, technological laws and socio-technical understanding [6]. There are numerous classifications but they are partially redundant (what is the difference between procedural knowledge and technical know-how?). Each author provides a different classification and it is difficult to get an overview of the types of knowledge involved in the design process. Furthermore, the types of knowledge provided in the literature are usually very general. What is included in technical know-how? Could technical know-how be further specified in e.g. product know-how, design process know-how and manufacturing process know-how? Could product know-how, design process know-how and manufacturing process know-how be also further specified?

In order to get an overview of the types of knowledge in engineering design, we conducted a literature review searching for classifications of design knowledge. We analysed the classifications to identify what were the similarities and differences between those and we came up with a taxonomy to classify design knowledge in dimensions with their corresponding characteristics.

The paper is structured as follows: Sect. 2 exposes the definitions of key terms for our work; Sect. 3 describes the procedure for our literature review; Sect. 4 presents the results; Sect. 5 states the conclusions; and further work is described in Sect. 6.

2 Definition of Main Terms

Three terms appear constantly in knowledge management literature and should therefore be defined. Those terms are data, information and knowledge, as well as the relations between them. [7] defines data as “unorganized and unprocessed facts”. Information is for them “the aggregation of processed data which makes decision making easier”. They define knowledge as “evaluated and organized information that can be used purposefully in a problem solving process”. Numerous authors provide similar definitions, whereas some others do not even agree that knowledge can be codified. These authors claim that knowledge exists only in the mind of people and not in any form of written document. For them, all that is written is information [8].

On the other hand, there are also numerous authors that do not try to strictly separate the terms and they treat them indistinctly. Reference [9] defines knowledge management as the discipline that "promotes an integrated approach to identify, capture, evaluate, retrieve, and share all of an enterprise's information assets. These assets may include databases, documents, policies, procedures, and previously un-captured expertise and experience in individual workers". Reference [9] establishes in this definition no difference between knowledge, information or even data. For our literature research, we also consider knowledge and information indistinctly, as many authors did not expose the definitions of the terms they used in their publications.

3 Procedure for the Literature Review

We reviewed over 800 publications searching for classifications of design knowledge. Since our purpose was summarizing the variety of types of knowledge that have been already identified, we did not look into documents containing knowledge itself (like patents or design reports) but we looked into scientific publications that try to classify and work with those types of knowledge. The publications were extracted from Google Scholar, Scopus, Web of Science and the library of the Technical University of Munich (TUM) between October 2015 and April 2016. Table 1 depicts the searches. All the selected publications cannot be referenced in this paper due to place constraints, but we show the number of publications to give the reader an idea of the research extension.

From the reviewed publications, we selected 95 that explicitly named types of design knowledge. We discarded the sources that did not clearly define which types of knowledge they considered for the work.

4 Literature Review

4.1 Results

We have classified the selected publications according to the product they develop (i.e. type of industry). We decided to do that because the type of industry was usually well defined in the publication and we were interested to see if there were differences between the types of design knowledge that different industries consider. Some of the types of knowledge named in the reviewed publications are presented in Table 2.

Table 1 Overview of the searches made for the literature review

Search words	Source	Sorted by	Number of results	Re-viewed	Selected
Knowledge management	Google scholar	Relevance	3,960,000	100	8
Types of knowledge in engineering design	Google scholar	Relevance	3,210,000	200	7
Types of knowledge depending on the owner of the knowledge	Google scholar	Relevance	269,000	60	3
Product knowledge in design engineering	Scopus	Relevance	6335	20	2
What are the product knowledge necessary in design phase of a product	Google scholar	Relevance	2,540,000	30	2
Tacit and explicit knowledge in design processes	Google scholar	Relevance	186,000	30	1
Design engineers and technical professionals at work	Google scholar	Relevance	1	1	1
Knowledge in engineering design	Scopus	Relevance	30,372	103	4
Customer knowledge in product engineering	Google scholar	Relevance	983,000	30	1
Reuse knowledge in product engineering	Google scholar	Relevance	474,000	50	2
Internal and external knowledge in engineering design	Google scholar	Relevance	1,090,000	10	1
Reuse knowledge in engineering design	Google scholar	Relevance	30,372	200	11
What knowledge is needed to design a product	Scopus	Relevance	945	50	4
Organization information of product engineering	Google scholar	Relevance	1,290,000	80	5
Innovative knowledge of product engineering	Google scholar	Relevance	1,220,000	20	1
Knowledge in product design	Web of science	Relevance	4,360,000	100	6
Knowledge identification in design engineering	Google scholar	Relevance	2,610,000	90	2
Experience knowledge in engineering design	Scopus	Relevance	4752	15	2
Search for specific titles or books	TUM	–	–	–	32

In total we obtained 48 types of knowledge from publications that did not specify the product they referred to, 30 types of knowledge from the field of electromechanical product development, 10 types from structure engineering, 15 types of knowledge from mechanical product development and 10 types of knowledge from publications dealing with other products (chemicals, plastics, etc.).

Table 2 Examples of the types of knowledge found in the literature for each type of industry

Type of industry	Type of knowledge	Author
Product not specified	Learning by doing	[10]
	Competitor knowledge	[10]
	Human knowledge	[11], [5]
	Codified knowledge	[12]
	Tacit knowledge	[12]
	Process knowledge	[13]
	Object knowledge	[1]
Electromechanical	Knowledge contacts	[14]
	Interactions, trade-offs and design rules	[14]
	Explicit knowledge	[15, 16]
	Design process knowledge	[15]
	Typical values	[16]
	Experiential knowledge	[17]
	Tacit knowledge	[17]
Structure engineering	Internal knowledge	[18]
	Social knowledge networks	[18]
	Engineering actors	[19]
	Fundamental design concepts	[19]
	Customer knowledge	[20]
	Internal sources of knowledge	[21]
	External sources of knowledge	[21]
Mechanical products	External knowledge	[22]
	Knowledge process	[22]
	Personal knowledge	[23]
	Process knowledge	[24]
	Competitor knowledge	[24]
	Realization knowledge	[25]
	Declarative knowledge	[25]
Other products	Explicit knowledge	[26]
	Implicit knowledge	[26]
	Tacit knowledge	[26]
	Fundamental design concepts	[27]
	Criteria and specifications	[27]
	Practical considerations	[27]
	Technology knowledge	[28]

We did not identify any remarkable difference between the types of knowledge named in each type of industry. The types of knowledge were mostly described in a generic way that could be applicable to all groups. Types like internal/external knowledge, tacit/explicit knowledge were found in all types of industry. Types of knowledge more specific to engineering design like design process knowledge or fundamental design concepts were also expressed in those terms, applicable to all types of industries. For this reason, we did not further consider the separation depending on the product to be developed.

4.2 Summary

Analysing the types of knowledge compiled, we realized that some ways of classifying knowledge in literature were not mutually exclusive but they complement each other, i.e. the same knowledge can be classified at the same time in more than one way (e.g. knowledge can be simultaneously explicit and external). However, there are also mutually exclusive ways of classifying knowledge (e.g. knowledge cannot be at the same time explicit and tacit). Given these possibilities of combination, we summarized the results of the literature review in a taxonomy (Fig. 1). A taxonomy is defined as an "ordered arrangement of groups and categories" [29]. We considered five groups that we named "dimensions" and that are complementary, i.e. any piece of knowledge can always be classified in all dimensions. For each dimension, knowledge can be classified in one category of the dimension. The categories are mutually exclusive, i.e. in each dimension knowledge can only belong to one category. Thus, the way of reading the taxonomy is like a morphological box, well known in product development [30].

To come up with the taxonomy, we first grouped all types of knowledge that were similar, paying special attention to those types that meant the same but were named differently. Table 3 shows how we proceeded to determine the dimension "concretization level". An example of how we clustered is the case of basic, principal, general, elementary, generic and fundamental knowledge. We grouped these types of knowledge together because we considered that the authors that named those categories referred to the same type of knowledge. The second step was to assign names to the clusters. In this case, we assigned the name "general

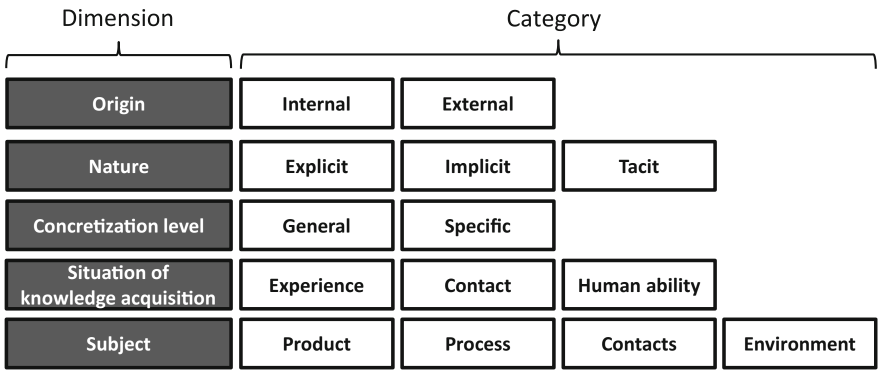

Fig. 1 Taxonomy of types of knowledge in engineering design

knowledge". Finally, we proposed the dimensions that embrace the categories established. Thus, in this case, we realized that "general knowledge" and "specific knowledge" are mutually exclusive and we assigned them to the dimension that we named as "concretization level". We proceeded in this way to determine all dimensions and categories. The complete results cannot be exposed due to place constraints. Table 3 serves as an example to show the procedure.

The dimension "origin" defines where the knowledge comes from in the company. It can be categorized as internal to the company, like project reports or new ideas from R&D departments; or external to the company, like knowledge obtained from research articles or customers.

The dimension "nature" defines the essence of the knowledge. Explicit knowledge is documented whereas tacit knowledge is not articulable and it exists only in people's mind. Implicit knowledge is knowledge that has not been articulated and thus it is still in people's mind but it could be possible to articulate it.

The dimension "concretization level" defines how specific is the knowledge. General knowledge is independent of the domain, i.e. it does not belong to a specific business. Specific knowledge is particular to an industry or a product.

The dimension "situation of knowledge acquisition" describes in which activity was the knowledge gained. Knowledge can be the result of experience, it can be transferred from a contact (either person or document) or it can be inherit to the abilities of a person.

The dimension "subject" defines to which entity the knowledge is referring to. In the case of engineering design, four subjects were identified: knowledge can be about the product to be designed, about the process (either the design process and its activities or the manufacturing process of the product), about contacts, i.e. stakeholders related in some way to the product, and about the operational environment of the product. Further specifications of the categories of the dimension subject are presented in Table 4. The procedure to determine the subcategories was the same as the procedure followed to establish the other dimensions and categories.

Table 3 Categories of the dimension "concretization level"

Category	Type of knowledge named in literature	Author
General knowledge	Basic knowledge	[14]
	General design knowledge	[1], [31]
	General process knowledge	[32]
	Principle knowledge	[33]
	Elementary knowledge	[34]
	Fundamental design concepts	[27]
	Generic knowledge	[22]
	Specialist knowledge	[14]
Specific knowledge	Specific knowledge	[1], [22], [34]
	Domain-specific basic knowledge	[32]
	Product specific parameters	[14]

Table 4 Categories and subcategories of the dimension "subject"

Category	Subcategory	Sub-subcategory
Product	Constraints and specifications	
	Conceptual	
	Structural	
	Functional	
	Behavioral	
	Technical	
	Calculations	
Process	Manufacturing process	Installation requirements
		Realization
		Practical considerations
		Technology
	Design process	Realization
		Practical considerations
Contacts	Supplier	
	Customer	
	Competitor	
	Other stakeholders	
Environment	Legislation	
	Country/market	
	Environmental entity	
	Product lifecycle	

5 Conclusions

This paper presents a review of the types of knowledge considered in engineering design literature. The following conclusions can be extracted:

- The terms information and knowledge are often used indistinctly in literature.
- The types of knowledge named in the literature are abstract and generalizable.
- Some types of knowledge are complementary, i.e. a piece of knowledge can be categorized within both types at the same time.
- Many types of knowledge are named differently in the literature but they can be considered synonyms.
- The dimension "subject" is more named and specified in literature than the other dimensions.

The results are summarized in a taxonomy that represents an overview of the types of knowledge found in the literature. The types of knowledge in the taxonomy are not redundant and they are specified as much as possible for the field of engineering design. We could not point out differences in the types of knowledge for the different industries because the specific knowledge for each industry was not named in the literature.

The dimension “subject” is the only one that could be subdivided, because for this dimension the number of sub-classifications in literature was remarkably higher than for the other dimensions. This seems to indicate that this dimension is more relevant to be considered for engineering design than the others.

The taxonomy enables the classification of knowledge from different perspectives. For example, an employee of company A classifies as “internal knowledge” the knowledge available in company A, whereas an employee of company B classifies the same knowledge as “external knowledge”. The type of knowledge depends on the point of view of the classifier.

The paper at hand contributes to the research community providing a summary of a large amount of hardly comparable literature findings aligned in one unique publication. The taxonomy provides a theoretical base for researchers and practitioners dealing with knowledge management in engineering design, in order to select the right way of classifying knowledge for their purposes. Another use of the taxonomy is to classify the knowledge of a company in order to match it with the situations during the design process that each knowledge type can support. Design situations, characterized by their i.e. design phase, available time or personality of the designers could be matched with the most appropriate knowledge type to support them.

One limitation of the taxonomy is the subjectivity in the analysis of the literature findings. We had to interpret the meaning of the knowledge types in order to cluster the types of knowledge to create the taxonomy. Besides, the completeness of the taxonomy is limited to the reviewed literature and therefore, types of knowledge may be missing. For example, for the dimension “process” only “design” and “manufacturing” were explicitly named, but there are other processes involved in the life of a product. If the other processes can be included in a sub-category of “design process” or if they should be added as new categories of the dimension “process” must be clarified.

6 Further Work

The taxonomy should be validated with industry experts with two main objectives: (1) check understanding by practitioners; (2) identify new dimensions or categories that may not have been addressed in the reviewed publications.

It will be also investigated which ways of classifying knowledge are appropriate for which purposes of knowledge management. For example, classifying knowledge according to its origin can serve as the basis to define a strategy for open innovation, while classifying knowledge according to its situation of knowledge acquisition can serve to establish training or mentoring programs for knowledge development.

Ways of automatically matching the knowledge types with the design situations will be explored considering machine learning tools like Bayesian networks or artificial neural networks. The classification of knowledge in a taxonomy may be too restrictive to depict the numerous relations between the types of knowledge. In this case, it will be considered pushing the taxonomy towards an ontology.

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Approaches to Parameterization in Architectural Design

K. Anil Kumar and P.S. Chani

Abstract With computational capabilities parametric architecture has opened new domains of possibilities. The outcome of parametric approach can fit in any of the traditional classification in the architectural domain. But the approaches to parameterization in architecture vary widely, which can be broadly classified into form imitation, form optimization and form finding. These application areas are 'tool and technique oriented', 'problem solving oriented' and 'explorative approach' respectively. Any particular design case can have a combination of these approaches. In this paper these approaches are described, illustrated and parallels are drawn across these categories for comparison of these approaches. Further, based on this study, the design process is mapped in relation to parametric data flow in each of the approaches.

Keywords Parametric architecture · Design classification · Design data flow · Comparison

1 Introduction

With advancements in computer usage in design processes within architectural realm, there is a newer approach to design development which is parametric design process (keeping aside the tools that just imitate manual drawing (CAD) and reality (BIM)). While the traditional design process involves visually anticipating/deliberate design moves; the parametric design process involves logic/coded (non-visual) design moves, thus distinguishing from the traditional design process. This paper analyses different approaches for parameterization in architecture.

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1.1 Parametric Architecture

Parametric architecture/design is about designing with help of parameters. In this process parameters are defined with design concerns and manipulation of these parameters affect design in itself.

Peter Szalapaj in his book on contemporary architecture and digital design process defines parameterization as “Parameterization is concerned with the manipulation of variables within mathematical functions. The manipulation of such variables leads to the generation of a range of possibilities, and is particularly useful in systematic control of complex curved surfaces” [1].

Parametric design is not a new concept and has always formed a part of architecture and design. The consideration of changing forces such as climate, setting, culture, and use has always formed part of the design process. But the flexibility that we got with parametricism applied to computers and supported with allied activities makes it an area of interest.

1.2 Parametric Design Process

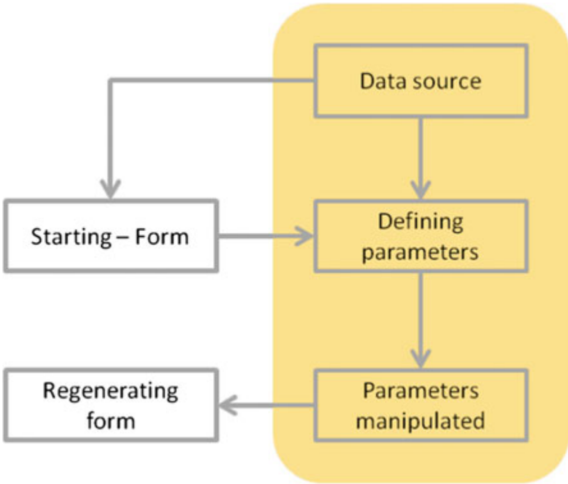
As described in various definitions and descriptions of parametric design process, including that of Peter Szalapaj as mentioned above, the key point is about manipulation of variables which are parameters of the design. With parameters an interrelated data model and dependencies are defined and developed along with relation to form which becomes the basis of form/design evolution. This has three stages (Fig. 1).

- **Defining data sources** which are the design environment, the base form, design guidelines/inspirations and performance capabilities of elements or subparts
- **Establish relations** between different data sources to make a **data model** and thereby define parameters that affect design
- **Change parameters** as per requirement and see how other data values are changing, from which designed form is regenerated.

Thus a major part of the parametric design is data management. The sources for these data are, the environment in which the design operates, the inspirational or selected object or pattern from which the data is deduced and finally the manipulation or the mathematical operations. Once an architectural form is generated there is data associated with these forms.

Data associated with architectural form includes, geometry of form, the structural data associated when these forms, material properties used for construction, thermal and energy analysis of the form in its context (design environment data), non-quantifiable aesthetic aspects of the form etc.

Fig. 1 General flow of data in parametric design process



In this parameterized approach to design, with the help of integrated model the source parameters are manipulated. The manipulation of parameters is done to see how the form along with data associated is changed to get the desired design output.

2 Different Approaches

Projects in architecture can be classified in many ways like architectural style, the scale of the project, type of ownership (public, semipublic, private), land use, construction technique and so on [2]. With usage of parametric techniques, the output can be of any nature. The outputs cannot be put in any of the classification as mentioned above as the final designs cannot be exclusively defined in any of these groups. In this paper approaches to architecture are classified on the basis of the purpose for which these tools are used for. They are form imitation, form optimization and form finding exercises. Design translation into a final product from idea can either be very direct as form imitation or a very complex translation through metaphorical interpretation. If the translation is very direct and form imitative, then it is already a known form and it becomes majorly a mathematical equation finding exercise and its adoption to architectural use (example of Frank Gehry's fish). In complex interpretative translation parameterization can be used in form optimization or very specific task within the process (example of roof section form finding and optimization in Sir Nicholas Grimshaw's Waterloo international train station). There is a complete different category where the constraints in the design brief is so complex that it demands a complete parametric approach where simple manual form finding does not work (example of roof geometry of the Great Court in British museum designed by Sir Norman Foster).

2.1 Form Imitation

Architects in their continuous search for new forms get inspiration from different sources. The sources of inspiration can be as varied as some living organisms, natural landscape or even art and sculptural forms either designed by them or others. Some design processes just take these inspirational forms as just metaphors while some others adapt and imitate these forms in their designs. Examples in the context of architecture can be works of Frank Gehry, where he makes sculptural forms and translate them into architectural designs.

The process of form imitation has six stages. They are

- Pre-study
- Selection of inspired form
- Study of inspired form
- Adoption of form to design context
- Rationalization of design
- Final design

The pre study includes the design requirements, desired behavior of required products, general awareness about the context of design, general areas where similar behavior is seen (method of TRIZ) and so on. This pre study is followed by selection of inspirational form. This selected form can be anything as mentioned above.

The study of inspired form consists of two parts. One that of physical attributes of the form and secondly the hidden attributes of form that allows that form to behave in a particular manner. The physical attributes include the form itself, the geometry, its organizational configuration, etc. The hidden aspects include the material, formative procedures, its structural behavior, etc. These two parts of study are reflected in the next stages i.e., adoption in design context and rationalization of design.

Adoption of form in a design context includes scaling the form, fitting the scaled form in actual design context, locating the places where the form has to be modified and doing the desired modification. Rationalization of the form include achieving the desired performance in the design environment (in terms of energy, structural performance, etc.), developing desired design language merging the imitated form with rest of the design (Fig. 2).

Example of form imitation (in the domain of architecture): Sculptural imitation is widely practiced by Frank Gehry in his office. Example of this is most of his works. Every model and sketch that are drawn are scanned and made as a vector and connected into a vector model, thereby controlling the accuracy of the scanning process. Once the model is complete the elements are parametrically controlled and manipulated to evolve design. Here the major use of parameterization in the design process is mainly present in the program path. The program converts the design into a set of NURB splines [1] which is manipulated by the designer using user

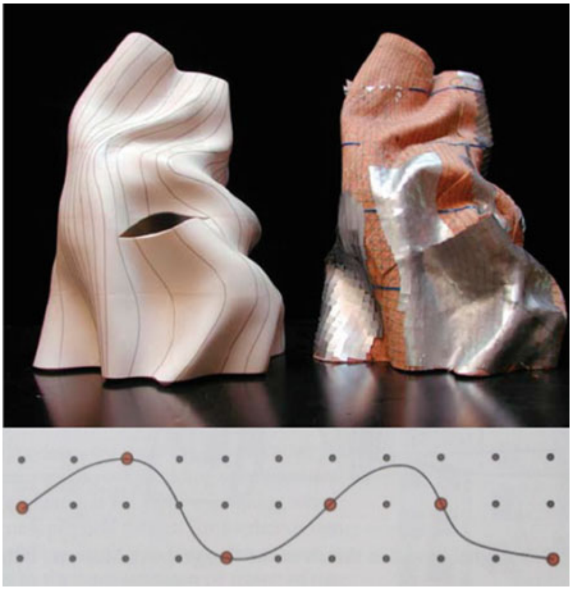


Fig. 2 Fig. 2a: digital reconstruction of model showing surface contour as splines Source: [3]; Fig 2b: Curve obtained by interpolation of known data points with B-splines. *Source* [1]

interfaces. The program of modified CATIA specially made for Gehry's office is based on parametrics [3].

2.2 Form Optimization

In case of Form optimization there is already a designed form or a design strategy. This strategy is used for constrain-dependent form modulation. This is more about refining a design rather than designing itself. The process of form optimization comes as an intermediate step in the process of design. The designed object refines its form and shape in the constrained environment it is modelled in. The acquired shape is documented and translated to full scale (Fig. 3).

Fig. 3 London Waterloo terminal. *Source* Architect sir Nicholas Grimshaw's website [4]

Example of form optimization: Another example of form optimization can be roof of waterloo station. The roof is 400 m long. The span of the roof varies from 50 to 35 m in span [4]. The roof is made asymmetrical for the site constraints. The western end of the roof has to rise steeply in comparison with eastern end to accommodate train below thus making the section asymmetrical. The section of the roof is a double arch, which is three pinned. Since the design is required to be streamlined as per the site profile and has a condition to fit train (train clearance height). Thus roof design has a base geometry (which is a double arched curve) and condition (fit train below) which was optimized parametrically (parameters are changing width of span, path in plan and height of arch) [1].

2.3 Form Finding

The form finding approach was discussed in the context of 'digital morphogenesis', 'computational form finding' by many authors. Form finding process is described by Kolarevic as "Instead of modelling an external form, designers articulate an internal generative logic, which then produces in an automatic fashion, a range of possibilities from which designer could choose an appropriate formal proposition for further development" [5].

Form finding is the most commonly used applications. This has been highly popular in the young student group [6]. Parametric approach to architecture is introduced for form finding by Gaudi in his catenary arch design to get exact shape and geometry of the structure. This is an explorative approach and includes the following methods.

- Process to author forms
- Algorithms
- Program generation
- Constrain based approach
- Structural logic
- Environmental
- Material constrains
- Site constrains
- Geometrical experimentation

Example of form finding: The Roof of the Great court in British Museum, London is a case of form finding and form optimization as well. Overall generation of shape is a case of form finding while deciding an optimum grid size based on available glass sizes is a case of form optimization (Fig. 4).

The existing building over which the roof is proposed, gave designers complex conditions to design. The existing buildings could not resist horizontal thrusts from the arch action of any new roof. The survey reveals that center circular building is not in center of outer building. The site also has height restriction as the dome

Fig. 4 View of the Great Court in the British Museum (*Source* Architect Sir Norman Foster's website) [7]

above central library should not be dominated visually. The roof should be light weight to retain the splendor of reading room. The design has to retain existing classical Georgian facades [7].

The structural constrains led to adoption of a specific phenomenon (stress-controlled surfaces) developed from Frei Otto's experiments [1]. The adopted phenomenon and overlap of three layered grid are merged to develop mathematical equations. The variables in the equations are parameters. Due to its site conditions each joint was also designed separately, thus from design conception to detailing, parameterization was used to make the design possible. The resultant structure is made possible with other allied activities of structural analysis and manufacturing aids which were integrated in the parameterized process.

3 Comparison of the Above Discussed Approaches

The above mentioned approaches are compared under different aspects in Table 1.

Table 1 Comparison of parametric approaches

	Imitation	Optimization	Finding
Kind of input data	• Geometric information • Design functional requirement • Environment physical properties	• Base form • Rules of design environment	• Inspirational source • Interpretation • Transformation strategies [9]
Activities undertaken	• Form digitization • Scaling	• Extract environmental rule determinants from form • Check validity and performance	• Explore from start point • Anticipate results in each direction
Goals of approaches	• Embed one into other	• Find common domain	• Series of actions • Develop process of defining form
Variation generation	• Scale variation • Exception location • Assembly system • Component relation	• Variation of each parameter wrt effect over result • Balance among parameters	• Strategic variation • Diversified exploration • Process imitation
Analysis of generated	• Scaling vs functional satisfaction vs similarities of source and final form [1]	• Satisfies rules of environment or performance, [10] • Trends of results in parametric variation	• Process of form development, series of actions to do to result in form, direction of exploration
Advantages of parametricism in doing actions	• Precise construction data • Flexible transformation at any point	• No repetitive actions • Precise real time calculation with change in parameters	• Extra set of tools of relate and repair other than add and subtract [11] • Ability to change strategy
Major challenge	• Test materials to its extreme • Work across scales	• Defining rules of environment • Bridging rules with built form parameters	• Varied direction of exploration • Complex forms at the end of the day
Role of contributors	• Less application of parametrics by designer • Highly evolved software necessary	• Designer highly involved in simulating environment • Program is only a platform • Bridge between software's crucial	• Completely dependent on designer • Programs preset commands are helpful
Direction	• Form oriented • Conditional satisfaction • Design by chance [8]	• Element performance oriented • Conditional satisfaction • Systematic approach	• Design oriented • Transformation centered • Design by chance [8]

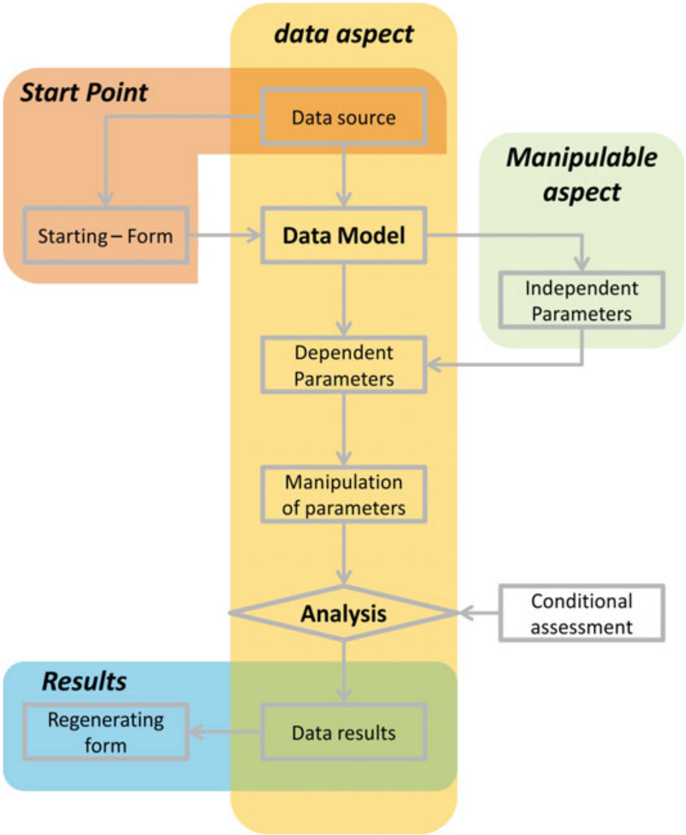


Fig. 5 General design process in parametric approach

4 Design Process Along with Data Flow in Each of the Approaches

The whole process of design in parametric approach is shown figuratively in the Fig. 5 flowchart. This flow chart has three parts, which are the start point, the data processing and the result. The base form or pattern from which design evolves becomes the start point. Along with the base form there is a set of data as input. The form and the data are associated together to form an integrated data model. The independent parameters and thereby dependent parameters are identified. The independent parameters are modified so as to make dependent data values perform in a specific manner.

The conditional assessment requirement determines the range within which the results are supposed to be. If the results are not in that range, then parameters are

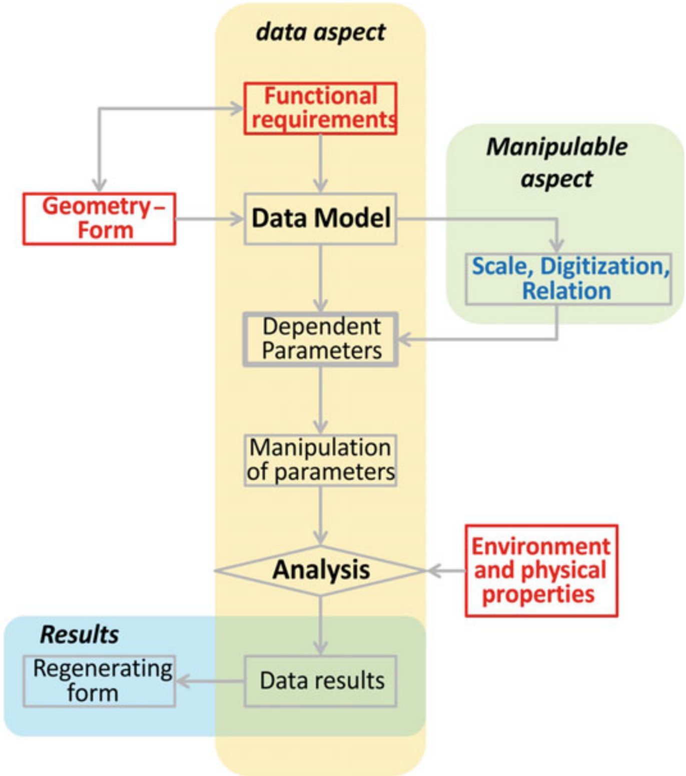


Fig. 6 Design process in form imitative approach

changed so as to bring the results within that range. These results are converted back as form or conclusion drawings.

4.1 Design Process in Form Imitative Approach

In the process of designing with form imitation one starts with the form, its properties one side and the design functional requirements on the other side. A balance is to be achieved with both of these. The manipulable aspects in this process are the digitization of forms, scaling of forms and manipulating relations. This digitized, scaled and manipulated form is analyzed for the environment and physical properties. The final data generated leads to final form. This is illustrated in Fig. 6.

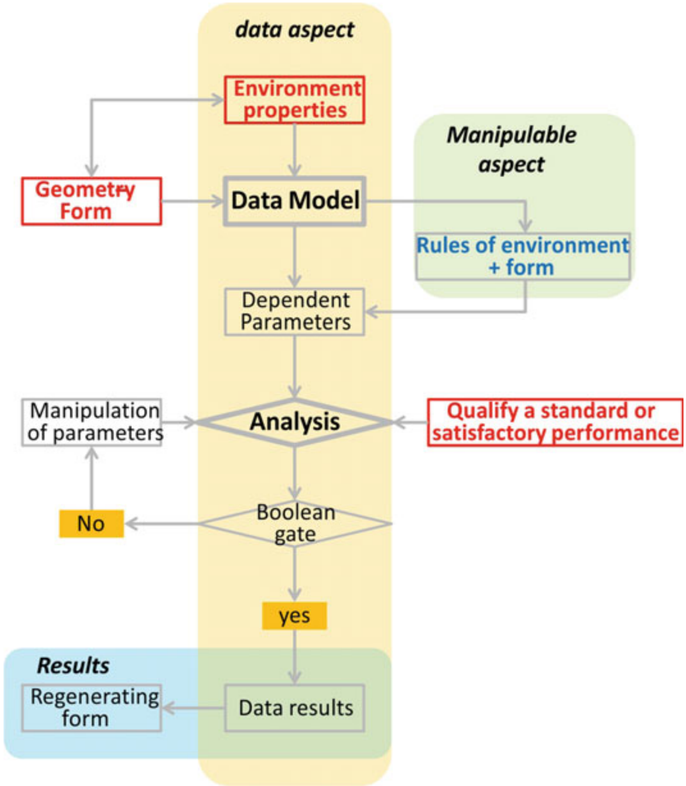


Fig. 7 Design process involving parametric form optimization approach

4.2 *Design Process Involving Parametric Form Optimization*

In this case there is already a form to start with. The environmental properties or the design conditions are the determiners. The flow of data through the processes is shown in the Fig. 7. Unlike in the case of form imitation where we have the required form, here we have approximate form, which is let modified in a constrained manner. The modification here controlled by manipulating the rules of environment. This exercise is to attain balance between form and satisfactory performance (either in terms or quality or in terms of performance) in its design environment.

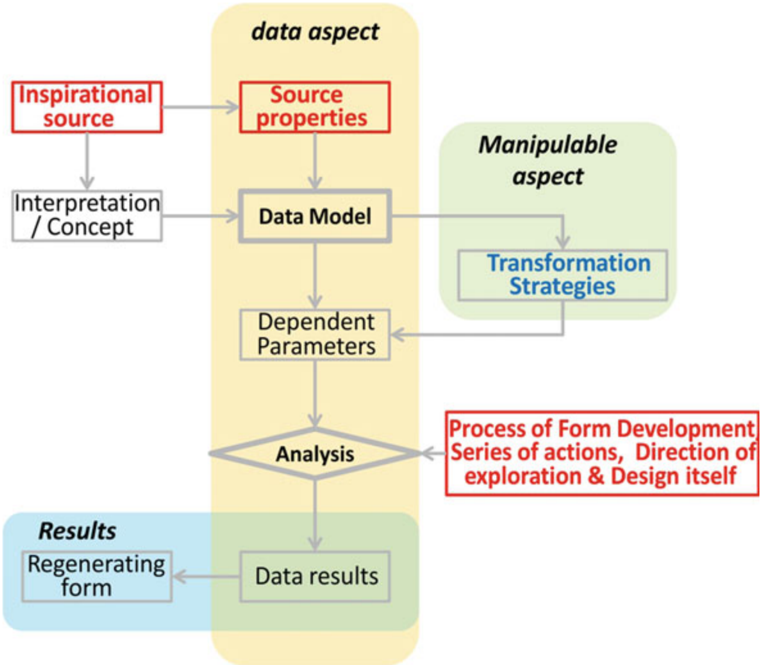


Fig. 8 Process of form finding

4.3 Process of Form Finding with Parametric Tools

Here the designer has the inspirational source for design. The designer takes the source properties and interprets and conceptualizes to start in his explorative path. The conceptualized inspirational model is transformed and articulated to get the desired results. This process unlike the other two processes doesn't have definite path or form. Here the designer let the process or the environment or the concept generate form. These transformational strategies and direction of exploration are determined by designer. With a minor tweaking of parameters in the process the design output is varied. Thus many iterations are produced from which the designer chooses the desired (Fig. 8).

5 Conclusion

This paper has three parts. The first part introduces and describes the three design approach categories and the second part compares different aspects in these three aspects. This study reveals that each of the approaches have distinguished design and dataflow paths. The parametric aspects are handled by both program part and designer. In form imitation process, the use of parameterization is mostly in the program path but deliberated and manipulated by designer; while in the other two approaches the designer has greater role. In imitation kind of processes, parameterization can be used in an advantageous way for geometrical & enabling analysis. Form Optimization is mostly a refining process. It is mostly to find the common domain between the performance of the model and rules of design environment. Form finding process, though can be done in non-computer methods like Gaudi's catenary arch or Frei Otto's bubble experiments, is done using algorithms along with computational capabilities. While imitation process is centered around the form, focusing on tools and technique; the optimization process is centered at the elements performance, in a problem solving orientation; and form finding around designing in an explorative manner.

In the final section, the design process is mapped in relation to parametric data flow in each of the approaches. This section highlights different steps involved in each of the categories of design process.

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Towards Automatic Classification of Description of Analogies into SAPPhIRE Constructs

Sonal Keshwani and Amaresh Chakrabarti

Abstract The motivation behind this research is to aid designers in retrieving a large number of analogies relevant to the design problem under consideration. The objective of the work reported here is to automatically classify natural-language descriptions of analogies into constructs of SAPPhIRE model of causality—a common causal language that was developed for describing the functioning of natural and artificial systems. This should provide the benefit of utilizing the enormous data available on the Internet, while also providing focused search results. Using supervised classification approach, the accuracy (cross-validation) achieved in classification of natural-language descriptions of analogies into the constructs of SAPPhIRE model was 0.70 ± 0.08.

Keywords Retrieval of analogies · Text classification · Biomimetics

1 Introduction

Design by analogy has been recognized by researchers as an important method for novel idea generation [1]. However, retrieval of analogies relevant to a given problem is limited by the knowledge of the designer [2]. Further, potentially there can be innumerable analogies available in books, web documents, etc. Therefore, a pertinent question for designers is where and as to how to search for analogies. As a result, retrieval of analogies is a challenging task for designers and has, therefore, gained the attention of researchers. The following two approaches have mainly been used by researchers to support designers in retrieving analogies: (a) creating a structured database of analogies and searching in this database for analogies (henceforth, denoted as Approach-1); and (b) searching analogies in natural-language text (henceforth, denoted as Approach-2). Approach-1 has the benefit of focused search [3], but is limited by the need for a manual process for structuring

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analogies into a database structured for efficient search [2]. Approach-2 has the benefit of the enormous data that is already available on the Internet, leading to a large number of search results [2]; however the results may include irrelevant results in large proportions [4, 5]. In order to have the benefit of both these approaches and to avoid their pitfalls, authors of this work propose to integrate them. The overall objective is to automatically convert unstructured natural-language description of an analogy into a structured description. As part of this overall objective, the authors have classified natural-language descriptions of analogies into the constructs of SAPPhIRE model of causality [6]. Analogies, in this work, belong to either natural- or artificial-systems. Here, 'natural-systems' are those that occur in nature and are not man-made (for example, insects) and 'artificial-systems', are taken as those that are man-made and belong to the domain of technical-products (for example, vacuum-cleaners).

2 Literature Survey

Literature is reviewed for approaches 1 and 2 in Sect. 2.1 and models of causality in Sect. 2.2.

2.1 Existing Approaches for Retrieval of Analogies

Using Approach-1, researchers have proposed computational tools that search across structured database of analogies. For instance, Chakrabarti et al. [6] developed IDEA INSPIRE based on SAPPhIRE model of causality and Vattam et al. [7] developed DANE based on SBF model; both have databases of natural- and artificial-systems, to aid designers in retrieving analogies. AskNature [8], an online repository of more than 1800 natural phenomena, is based on a biomimicry taxonomy of functions.

Similarly, using Approach-2, various research efforts have been made for retrieving analogies from natural-language text. For instance, Hacco and Shu [4] incorporated the use of Wordnet and part-of-speech tags along with keyword search method, to search for potential analogies in the index and glossary of biology text book. Verhaegen et al. [9] extracted product characteristics (PAs) from patent database and used them to identify candidate products for design-by-analogy. Vandevenne et al. [10] developed a webcrawler that continuously searches the Internet for biological strategies to update its knowledge base.

Approaches 1 and 2 above have been compared, in this work, on the basis of two criteria that were identified from literature [2–7]. The two criteria and the comparison between the two approaches on the basis of these criteria are mentioned below:

Criterion-1: Size of the source from where analogies (natural- and artificial-systems) are searched
'Source' is defined here as a repository from where analogies are searched by a tool. Having a greater size of the source is advantageous because the greater the size of the source, the greater will be number of analogies searched by the tool for a given problem. Further, greater size of the source may increase the chances of retrieving analogies for diverse design problems belonging to various domains. In Approach-1, the source is a database of natural- and artificial-systems that is structured into multiple abstraction levels using a common causal language. Increasing the size of the database is difficult in Approach-1 as the structuring of database is done manually. In Approach-2, the source is the natural-language description of text-documents available on the Internet. As the Internet has huge number of text-documents, the size of the source is much greater in Approach-2 than in Approach-1. Therefore, on the basis of Criterion-1, Approach-2 is more advantageous than Approach-1.

Criterion-2: Relevance of analogies searched for a given problem
Approaches 1 and 2 employ various methods to search for analogies across their respective sources. These methods filter out irrelevant analogies from relevant ones for a given design problem. In Approach-1, search can be more structured and performed at different abstraction levels, thereby providing focused search results. For instance, Idea Inspire supports simple-, combination- and complex-search [3]; where in simple- and combination-search, a designer can give either one SAPPhIRE construct or a combination of SAPPhIRE constructs as keywords for search; complex search means, for example, searching analogies that share the same Physical-Phenomena across analogies that fulfill a given Action [3]. In Approach-2, because of the huge amount of text data (as mentioned in Criterion-1) and the relatively less focused search methods, like simple keyword and synonym search [4], a large number of irrelevant analogies are also present along with relevant ones [4]. For instance, Glier et al. [5] reported that less than 30% of search results fostered ideation in their study. As providing relevant analogies is important for fostering ideation, on the basis of Criterion-2, Approach-1 is more advantageous than Approach-2.

As both the approaches have some advantages and disadvantages, the intent is to integrate these approaches to retain the benefit of both and avoid their pitfalls. This integration is intended to be achieved by using a common causal language to automatically convert natural-language descriptions of analogies into a structured entry in a database, and then support search for analogies across the database, thereby attaining the benefits of a richer and larger database as well as more focused search.

2.2 Common Causal Language

Chakrabarti et al. [6] reviewed the strengths and weaknesses of different models of causality, and combined these to propose SAPPhIRE model so as to provide a richer description of causal elements and relationships. The model was originally developed for supporting design by providing causal descriptions of biological and technical systems as stimuli for inspiring ideation for designers searching for solutions to design-problems. In this work, therefore, SAPPhIRE model of causality has been chosen as the common causal language to develop a structured database of analogies. The acronym SAPPhIRE stands for its constructs State-Action-Part-Phenomenon-Input-oRgan-Effect. The digits 1–7 in parenthesis in Fig. 1 denote the hierarchy in SAPPhIRE abstraction levels. The constructs are explained as follows: Parts consist of entity and surroundings. An entity is a subset of the universe under consideration, and is characterized by its boundary; surroundings include all the subsets of the universe except for the entity [11]. Components and interfaces that comprise an entity and its surroundings (i.e. *Parts*) have various properties and conditions (*Organs*). When the entity and the surrounding are not in equilibrium with each other, there is transfer of physical-quantities in the form of material, energy or signal (*Input*) across the entity boundary. These inputs, in combination with organs, activate principles (*Physical-Effects*). Physical-Effects are responsible for interactions (*Physical-Phenomenon*) between the entity and its surrounding. The interaction changes various properties of the entity and the surroundings (*State-Change*). The changes in properties can be interpreted at higher levels of abstraction (*Action*).

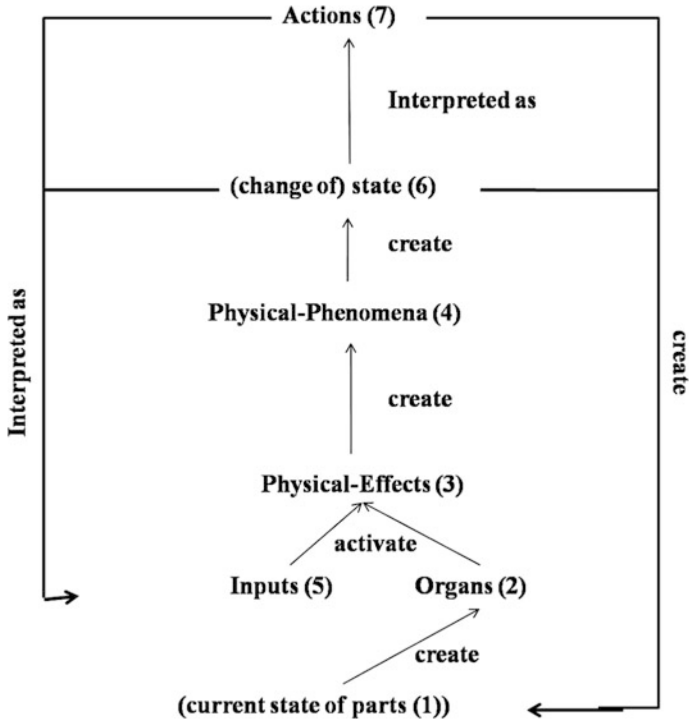

Fig. 1 SAPPhIRE model of causality. *Source* Chakrabarti et al. [6]

3 Research Question and Objective

From the issues raised above, the overall research question that is intended to be addressed is the following: How to automatically structure natural-language description of an analogy into the constructs of SAPPhIRE model [6]? Based on the above research question, the following is the associated research objective that has been addressed in this work: to automatically classify a natural-language description of an analogy into the constructs of SAPPhIRE model [6].

4 Methodology

This section presents the methodology proposed for achieving the above objective. Supervised learning method [12] was adopted for classification of natural-language description of analogies into the constructs of SAPPhIRE model. In machine learning, *classification* is the task of choosing the correct *class label* for a given input [12]. An example of classification task can be deciding whether an email is spam, where 'spam' and 'no-spam' can be two class labels of emails. This task of classification is performed by a function called *classifier*. In this work, the objective of classification is to select the correct SAPPhIRE construct for a given sentence or a phrase from a natural-language description of an analogy. The software packages used in this work for classification are as follows: Scikit Learn 0.17 [13], TextBlob 0.9.1 [14] and NLTK 3.0.4 [15]. Sections 4.1–4.2 present the steps of classification in this work. These steps are illustrated in Fig. 2.

4.1 Collecting Data

In order to enable a classifier to classify a text, it should be trained on *training data,* and then its performance should be tested on *testing data*. Both training and testing data contain text along with correct class label for each text [12]. In order to collect data for this work, four researchers having experience of working with SAPPhIRE model, searched about 150 documents belonging to either natural- or artificial-systems from the following references: (a) Encyclopedia.com [16], (b) Explain that stuff [17], (c) Idea Inspire database [3], [6], (d) How stuff works [18], (e) Physical laws and effects [19], (f) Wikipedia [20]. The criterion for selecting these references was that the documents in these references should not contain those sentences that do not belong to any of the SAPPhIRE constructs (for example, 'the same principle applies to the cars') in large proportions. These sentences, which did not belong to any of the SAPPhIRE constructs, were eliminated. The remaining sentences of these documents were labeled as either 'Part' or 'Organ' or 'Physical-Effect' or 'Physical-Phenomena' or 'Input' or 'State-Change'

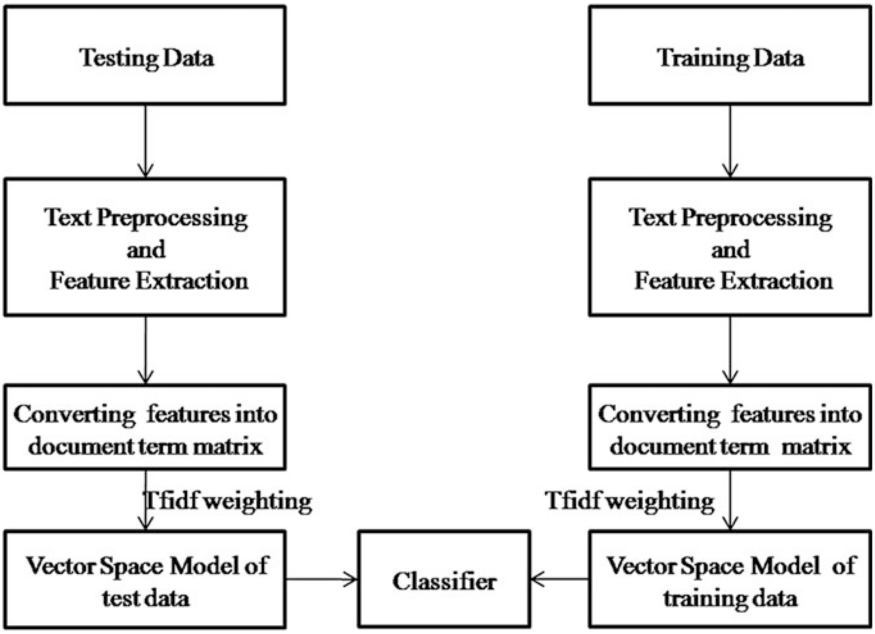

Fig. 2 Process model for classification of text-inputs into the constructs of SAPPhIRE model

or 'Action'. If a sentence constituted of more than one SAPPhIRE construct, then it was decomposed into phrases, each phrase belonging to a particular construct, for example, the sentence, 'The lack of limbs makes snakes slow-moving animals' was decomposed into phrases and labeled as follows: (a) The lack of limbs (Organ), (b) makes snakes slow-moving animals (Action). Henceforth, sentences and phrases that were collected for classification task in this work will be denoted as '*text-inputs*'. Approximately 250 text-inputs were collected for each SAPPhIRE construct except for Input and State-Change where the text-inputs were close to 80. This was because, occurrence of Input and State-Change text-inputs was relatively lesser than those of SAPPhIRE constructs in the documents searched. These text-inputs were then cross checked by the authors for any discrepancy in labeling. Further, it was observed that certain text-inputs belonged to a particular construct when they were considered with context and appeared to belong to other construct when considered out of context. For example, "motor is connected to battery" can be a Part level description, but in that context, it meant that motor is powered by battery, and therefore, it was an Input level description. Such input-texts were also eliminated. Inter-encoder reliability test was carried out for codification of labels of text-inputs using the method discussed by Blessing and Chakrabarti [21]. 27% of the text-inputs, were given to an independent encoder having over five years of experience on using SAPPhIRE model. Labeling done by the encoder was then compared with those done by the researchers. Overall, inter-encoder reliability was

Table 1 Number of text-inputs in training and test data for each SAPPhIRE construct

Data	Action	State-change	Input	Physical-phenomena	Physical-effect	Organ	Part
Training data	127	54	49	136	140	130	157
Testing data	50	24	24	50	50	50	50

initially found to be 71.38%. After discussion with the encoder on disagreements, it was then found to be 81.15%. 70% or above is the generally accepted threshold for inter-encoder reliability [21]. Overall data was, then, randomly divided into training and test data (Table 1).

4.2 *Text Preprocessing, Feature Extraction and Classification*

After the text-inputs were collected, they were preprocessed so as to make them usable for further steps. Preprocessed text-inputs were then searched for features that characterized each SAPPhIRE construct. *Features* highlight differences among classes, using which a classifier predicts label of a given input. Points 1–8 below explain the steps of text-preprocessing (Points 1, 3, 5, 6) and the steps of feature extraction (Points 2, 3, 7, 8), in the order of their implementation, using an example of a text-input T- "make sure that the two teeth strips enter at a specific angle":

1. **Word tokenization and POS Tagging**: The tasks of cutting strings into words [12] (word tokenization) and classifying them into their parts-of-speech [12] (POS tagging) were performed in TextBlob [14]. Example of text-input T: [('make', 'VB'), ('sure', 'JJ'),…] where, 'VB', 'JJ', etc., are the POS tags [22].
2. **Extraction of suffixes feature**: The following suffixes were extracted as features '-ment', '-nce', '-ion'. Example: As no word in text-input T has the suffixes '-ment' /'-nce', /'-ion', these features were not extracted from T
3. **Lemmatization**: The task of stripping off any affixes from a word and ensuring that the resulting form of the word is a known word in a dictionary [12] (lemmatization) was achieved using Wordnet lemmatizer. Example: 'make', 'sure', 'that', 'the', 'two', 'teeth', 'strip', 'must', 'enter', 'at', 'a', 'specific', 'angle'. Here 'strips' is changed to its base form which is 'strip'.
4. **Extraction of N-gram features**: "An n-gram is a contiguous sequence of n items from a given sequence of text or speech" [20]. N = 1, 2 and 3 for unigram, bigram and trigram respectively. The following N-gram features were extracted: word bigrams, word trigrams, POS tag bigrams, POS tag trigrams. Some examples of word bigrams in T are: 'make sure', 'sure that'.
5. **Word clustering for the constructs of SAPPhIRE model**: Using SAPPhIRE ontology [23], Wordnet [24], along with own experience of using SAPPhIRE

model, authors created clusters of words, characters and phrases that could occur at a particular SAPPhIRE construct. These words, characters, phrases were searched for across the text-inputs and replaced with the words marked in bold at the start of each cluster shown in Table 2. Example: 'If', 'that' 'the', 'Quantity', 'teeth', 'strip', 'enter', 'at', 'a', 'specific', 'angle'. Here, 'make sure' and 'two' are replaced by "If" and "Quantity" respectively.

6. **Stopword Removal**: High frequency words with little lexical content for example, is, the, and, etc. available in Stopwords corpus were removed. Example: 'that', 'the', 'at', 'a' words were removed from text-input T.
7. **Extraction of word unigram features**: Word unigram features were extracted. Example: 'if' 'Quantity', 'teeth', 'strip', 'specific', 'angle'.

Feature set so formed for each text-input, was converted into its document-term-matrix and tfidf-weighting was applied to create its vector space model. This vector space model of the training data was given to the classifier as input. In this work, Linear SVM (Support Vector Machine) classifier was used for classification. SVM is one of the best approaches used in the area of discriminative classification [25]. In this work, selection of N-grams as features for classification created a very high dimensional and sparse vector space. For this type of large sparse vector space, linear SVM classifier provides competitive and often better accuracy compared its nonlinear counterparts [25]. Therefore, Linear SVM has been used here for classification.

Once the classifier was trained, the above mentioned steps were implemented on the test data to predict the class labels (called here as 'predicted-labels') of text-inputs in it. For each text-input, the predictions made by the trained classifier were then matched against the labels assigned by the researchers (called here as 'actual-labels'). Based on the agreement between the actual- and the predicted-labels, the performance of the classifier was evaluated. Figure 3 illustrates a snapshot of classification of two text-inputs from the test data in this work.

Table 2 Clusters of probable words/characters/phrases at each SAPPhIRE construct

Action	[**Purpose**: purpose, objective, aim…], [**Purpose**: used to…]
State-change	[**Change**: change, decrease…] [**Change**: cut-down, trim-down…]
Input	[**Provide**: provide, inflow…], [**Provide**: hooked up, pump in], [**Source**: thermal, potential, kinetic…]
Physical-phenomena	[**Phenomena**: evaporation, condensation, repulsion…]
Physical-effect	[**Operators**: +, −, *, /, <…], [**Rule**: law, theory, principle…]
Organ	[**If**: less than, equal to, must be, make sure…]
Part	[**Connect**: connect, attach…], [**Quantity**: one two, million…],
Organ and input	[**If**: if, when…], [**Important**: necessary, requisite…]

```
text-input: resulting in solar modulation        actual_label=  action    predicted_label=  phenomena
text-input: used to achieve edge enhancement     actual_label=  action    predicted_label=  action
```

Fig. 3 A snapshot of class labels predicted by the classifier

5 Results

The performance of the classifier used has been measured using the following units of analysis: *precision, recall, f-measure* and *accuracy* [12]. The output of a classifier can be classified into true positives (tp), true negatives (tn), false positives (fp), false negatives (fn). Precision determines out of the total documents (here, text-inputs) that were classified as X, how many were actually X (Eq. 1) [12]. Recall determines the number of documents (here, text-inputs) belonging to class X, that were correctly classified (Eq. 2) [12]. F-measure is the harmonic mean of precision and recall [12]. Accuracy is the proportion of the number of correct classifications to the total number of classifications. In cross validation accuracy, data is segmented into k equal sized partitions. During each run, k − 1 partitions are used for training, while the remaining one partition is used for testing. This procedure is repeated k times so that each portion is used for testing exactly once [12]. Using Linear SVM classifier (at c = 2), precision, recall, f-measure and accuracy (stratified cross validation accuracy for k = 10) achieved were 0.71, 0.69, 0.70 and 0.70 ± 0.08 respectively.

$$precision = tp/(tp + fp) \tag{1}$$

$$recall = tp/(tp + fn) \tag{2}$$

6 Discussion

As far as the authors of this work are aware, in the domain of biomimetic design, no study has been reported that structures natural-language descriptions of analogies into a common causal language. The study closest to this work was by Glier et al. [5] who used the text classification approach, as used in this work, to classify search results as either 'helpful' or 'unhelpful'. Precision, recall and f-measure reported by them were 0.87, 0.52, and 0.65 respectively. Our results, we argue, are more evenly balanced in detecting both true positives and false negatives, as indicated by similar values for precision and recall. Further, classifier performance varies across domains. For instance, in the domain of face recognition, classification accuracy close to 100% was claimed to have been achieved on 600 FERET frontal face images [26], while in the domain of predicting stock data movements for different sectors, classification accuracy was reported to range within 59–79% [27]. Therefore, in the absence of reference data, benchmarking of results obtained from this work could not be done. In order to investigate errors in classification, the confusion matrix (Table 3) was analyzed. In this matrix, the diagonal elements represent the percentage of correct classification and the off-diagonal elements represent the percentage errors in the classification. Probable reasons for errors above 10% are discussed below.

1. 20% of Physical-Effect text-inputs were classified as Physical-Phenomena. Physical-Effects [6] include description of laws in nature, their equations and names assigned to that law, (e.g. Newton's Law). The classifier could classify equations and names of laws, but was not able to correctly classify description of laws, since that requires extra knowledge to identify that a particular description has been theorized in science. Otherwise, its features are similar to those of Physical-Phenomena, for example, "Theory of electrolytic dissociation states that molecule of an electrolyte can give rise to two or more electrically charged atoms or ions."
2. 20% of Action text-inputs were classified as Physical-Phenomena. Difference between Physical-Phenomena and Action is context dependent, based on overall action of a system. The current implementation does not capture context; therefore, Actions were classified as Physical-Phenomena, for example, "it displaces cold air in its path setting up convection current."
3. 17% of State-Change text-inputs were classified as Action. Action is an abstract interpretation of State-Change. This abstraction can again be at various levels, with lower level abstraction of an Action acting as a State-change to higher level abstraction of that Action, for example, "This leads to reduction in friction between interacting parts".
4. 17% of Inputs were classified as Organs. Input and Organs are prerequisites for activation of Physical-Effect. Therefore, the features of both of them represent some 'condition'. While Input condition is satisfied by 'inflow' of material, energy and signal from surrounding into the entity, Organ is the condition of component and interface between entity and surrounding. However, current implementation does not capture entity and surrounding boundaries, for example, "If the electroscope is given a known charge…"
5. 14% of Physical-Phenomena were classified as Part. Even though we attempted to decompose a sentence with multiple SAPPhIRE constructs into phrases, separation of Parts was difficult, as Parts can occur in any construct, for example, "Two metals in contact will also diffuse".
6. 13% of Inputs were classified as Physical-Phenomena. It was not understood as to why Inputs were classified as Physical-Phenomena. An example is, "After air enters the lungs". We think that this error occurred because of the relatively fewer Input text-inputs than those for other SAPPhIRE constructs.

7 Conclusions, Limitations and Future Work

This work is part of an ongoing research to automatically structure and populate analogies in the database of Idea-Inspire—a computational tool for assisting designers to access a large number of relevant analogies [3], [6]. Natural-language descriptions of analogies were automatically classified into constructs of SAPPhIRE model [6] using the supervised text classification approach. Using

Table 3 Confusion matrix (in %) for test data

SAPPhIRE constructs	Part	Organ	Physical-effect	Physical-phenomena	Input	State-change	Action
Part	(86)	2		8			4
Organ	8	(84)		6	2		
Physical-effect	6	6	(62)	**20**			6
Physical-phenomena	**14**	2	6	(66)	2	2	8
Input	8	**17**		**13**	(50)	4	8
State-change	8		4	8		(63)	**17**
Action	6	4		**20**	6	4	(60)

row reference, *column* test

Linear SVM, f-measure and stratified cross validation accuracy (k = 10) achieved were 0.70 and 0.70 ± 0.08 respectively. There are several limitations to this work. First, the data set used for training and testing is relatively small; because in the absence of a labeled corpus of SAPPhIRE constructs, labeling was done manually. Second, this implementation did not consider the context, i.e. entities surrounding boundary and knowledge of natural-laws, to distinguish between Physical-Phenomena and descriptions of Physical-Effects. Third, the references used for collecting data were not from peer-reviewed articles. The objective of data collection was to train the classifier so as to predict the constructs of SAPPhIRE model, using features to characterize the constructs. Future work includes automated decomposition of sentences into phrases, automated classification of phrases that are not SAPPhIRE constructs, benchmarking performance of classifiers with classification by experts, automated population of the database, and studying the influence of analogies in the database on novelty.

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Part IV
Design Aesthetics, Semiotics, Semantics

What the Statistics Tell Us—How to Use Empiric Data in Design for Emotional Impressions

Susan Gretchen Kett, Benedikt Schmitt and Sandro Wartzack

Abstract Looking at technical consumer products like communication devices or pc accessory, we state high saturated markets in developed societies. This leads to a broad range of market offers not only in performance or financial aspects. The users seek for more individual products that differentiate on a subsequent, more qualitative level. User centered design approaches have been developed to handle the resulting high product variety and to keep them economically efficient. E.g., Universal Design supports the development of products for as many persons as possible, also including those with physiological or cognitive deficits. But to really raise the quality of life we also need to take other needs into account. Maslow's hierarchy of needs states that with the fulfilment of physical needs the level shifts to psychological demands like emotional or attitudinal satisfaction. We will shortly introduce a framework that supports an emotional design optimization based on interdisciplinary findings (e.g. psychology, market research or Kansei Engineering) and statistical data analysis. For a valid forecasting, robust and transparent mathematical treatment of this data is required. To this, we give a first overview of possible approaches and their potential to ensure robust and transparent mathematical data treatment in design for emotional impressions.

Keywords Emotional engineering · Kansei engineering · User segmentation

1 Motivation

Companies of technical consumer products often deal with broad customer ranges in high saturated markets. Due to a fierce international competition and growing user demand for individualization, the product development is forced to both raise customer variety of choice and lower expenses by an appropriate product design. But it is no longer only the providing of functionalities the user asks for, but there

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are also other differentiation characteristics that influence the user's decision of use or non-use [1]. The product design is understood as a contribution to the user's happiness and thus to his or her overall quality of life [2].

Theory states that Quality of life is—apart from material and physiological satisfaction—also highly dependent from subjective well-being represented by the fulfilment of attitudes and values [3]. According to this, the value of technical products also strongly refers to these. The better the product developer is able to address the subjective requirements, the more the user values his product.

The product development process is a challenging task, facing restrictions such as time, cost, reliability, recyclability, manufacturability, etc. Therefore the consideration of emotional user needs must not hinder these processes or make the product unaffordable. This is rather difficult as human feelings or attitudes are complex and hard to gather [4].

In the following we present an approach how to measure and integrate emotional considerations for product development purposes. Therefore, several studies are conducted and analyzed.

2 Alternative User Segmentation in Product Development

From market research we already know strategies how to cluster user groups efficiently. This allows to lower diversity on one hand and to sharpen the focus for typical user requirements sets on the other hand. A cluster in user segmentation is characterized as a group of subjects who have remarkable differences to other groups but show high inner similarity to their own group [5]. One type of these segmentation strategies addresses socio-cultural milieus. Socio-cultural milieus include general value orientations, attitudes to family, leisure, money or habits [6]. Therefore they are particularly interesting for an alternative user description in product development tasks as attitudes and values of users represent a higher level of emotions but focus long time span at any given situation [7].

A vivid example to illustrate the importance of user attitudes and values in product development appeared in a study carried out. 25 PhD students (n = 25) in the design laboratory were asked to value their individual impressions differentials (see more in Sect. 3.1). The more, they had to pick out their favorite product out of a presented variations set of seven keyboards (p = 7). This user group is objectively highly homogenous. The participants were all more or less the same age, had the same financial income and the same educational background. But despite all expectations of their allocation in the socio-cultural portfolio, two instead of just one segment appeared (see Fig. 1). In the same row, the two groups would have chosen two different products. From a traditional point of view, we were not able to identify those clusters as the differences would have been superimposed by the dominant party (cluster 1, holding 2/3 of total). A considerable part of these users would hence have been sorely misunderstood in their product design preferences.

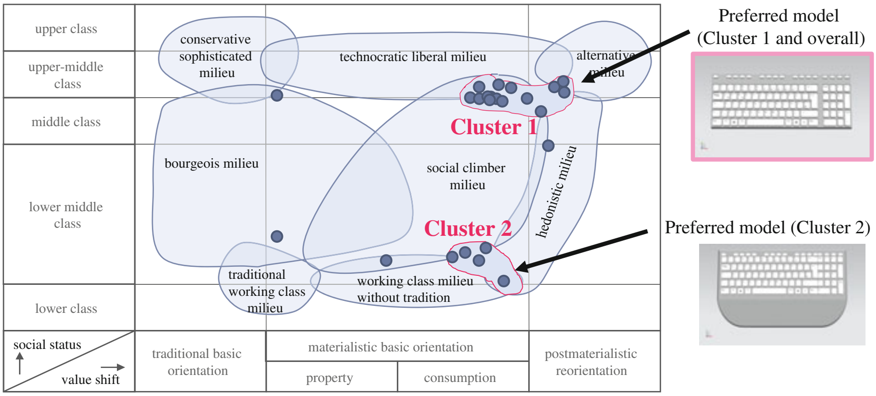

Fig. 1 Portfolio of a socio-cultural segmentation with two different clusters in the study (based on [8])

If we are now able to get access to the information provided by those segmentations representing attitudes and values of users and to translate them into product attributes, we will be able to better address specific user requirements. We would efficiently raise the subjective and thus the overall value of products.

3 Aggregation and Interpretation of Users' Attitudes and Values Using Empiric Data Analysis

ACADE (an Application for Computer Aided Design of Emotional impressions) is an approach that immediately links users' attitudes and impressions profiles to relevant product characteristics [9]. In this way, product segmentation can be aligned to the user segments, the product variety can be efficiently reduced by simultaneously better fulfilling the users' subjective requirements (see Fig. 2). Therefore, we use interdisciplinary knowledge to better understand the users' needs and values. The respective links between the involved disciplines will be introduced in the following steps.

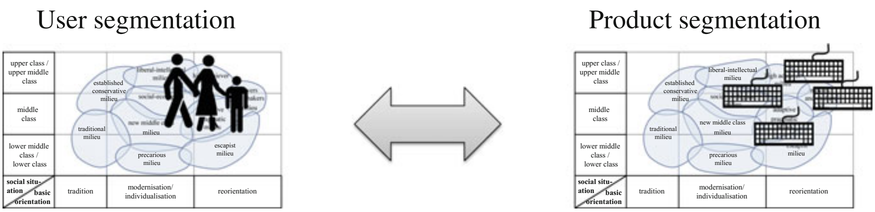

Fig. 2 The aim of ACADE is the alignment of product specifications to the users' attitudes and values in their respective socio-cultural segments

3.1 The Quantification of Users' Attitudes and Values

The first step is the quantification of parameters that characterize the user segments to enable mathematical treatment. Referring to FREY, the socio-cultural segments can be distinguished by their attitudes and values. These can be measured by so-called impressions differentials [8]. The smallest element of these differentials is a semantic differential, which is a pair of two opposite terms (e.g. "beautiful—ugly", "happy—sad") and can be weighted by interval scales [10]. The impressions profiles consist on an individual sequence of semantic differentials. An example is shown in Fig. 3.

This technique quantifies subjective impressions based on user attitudes and values and is thus of high relevance for product development strategies. But as product development targets a long term user satisfaction, repeated tests also show that the measured attitudes and values are highly reliable, so the profiling method is suitable for long-term investigations. We will therefore use this quantitative description to distinguish the social-cultural user segments in the design for emotional impressions.

3.2 Linking Emotional Impressions to Product Characteristics Using Hierarchical Product Description

Apart from user segmentation, the semantic differentials are used for subjective product characterization. This can be done by the users in the same way as the opposite word pairs can also be used for emotional impressions measurements. The benefit of this method is the detection of hardly determinable information referring to the specific product configuration. Normally, a customer does not say or even know what he or she wants. The more, he or she will not give answers in a structured and comparable manner that would be sufficient for product development issues. In the technical products field, we also need to address long term subjective product values that ensure the consistency to the user's attitude and values throughout the whole product life time. These are even harder to assess as they are of an indirect nature [7].

Besides an appropriate emotional impressions aggregation, we also need to control the changes made in the product's configuration. Only thus we are able to stringently investigate relationships between product form variations and the user's emotional impressions (Fig. 4). Due to the fact that the human perception highly depends on visual reception [11], measurements can be firstly reduced to visual

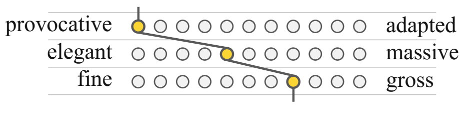

Fig. 3 Excerpt of semantic differentials that are combined to impressions profiles

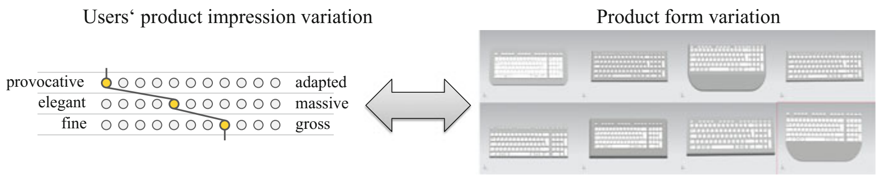

Fig. 4 Product characteristics and user emotional impressions variation based on Kansei Engineering in the keyboard example

appearances of the product. To change and to control specific product form parameters being relevant for the investigation, we presented a CAD-based product configurator based on matrix based product description [9]. The matrix based product description decomposes the product into properties and characteristics and enables an efficient data management [12]. In this, properties are defined as parameters like height, length or color that can be directly defined by the product developer. Characteristics are dependent from these properties representing multi-factorial dependencies between these. For example, a part's volume depends from height, length and width and cannot be directly set by the product developer [13]. But it enables to aggregate multiple factors to an overall phenomenon which is useful to assess different user impressions in product form variations. Applying the configurator and the impressions differentials, a stringent and robust investigation can be carried out.

3.3 Investigating Relations Between User Segments and Product Derivatives

We are now able to assess users' attitudes and values and to group users into defined socio-cultural segments. Moreover, we can create and manage product variations and link them to product properties.

The task is now firstly to create a link between those two data sets and, secondly, to assess how the measured impressions can be used to design products for specific target segments. The link between users' impressions and product parameter variations can be created by undertaking variation studies and deriving functional dependencies in these observations (see Kansei Engineering, e.g. in [14]). This offers potential to efficiently increase the automation level for an effective product development support. However, this does not yet answer the question, how the users and—lastly—whole target groups want their product to be like. For instance, it is not sufficient to know how much "sporty" the product looks, but it is even more important to figure out how much "sporty" the user wants it to be.

Hence, the users were all asked to arrange the product variations to their personal preferences by an additional question, (first = "I like most", last = "I like least"). Throughout all studies using the keyboard example (study #1: $n = 8$, $p = 20$;

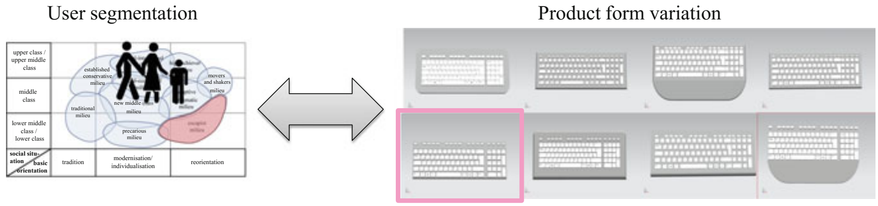

Fig. 5 Single user segments in social-cultural segmentation widely prefer the same product variant in the keyboard example

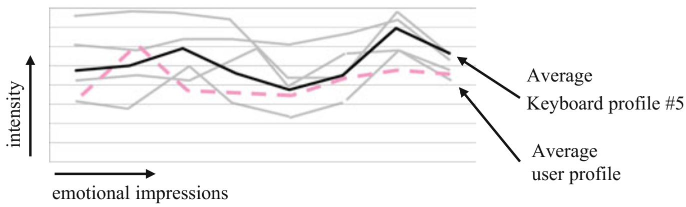

Fig. 6 Example of the empiric phenomenon that users instinctively prefer products that are most similar to their personal impressions profiles in one segment (n = 18)

study #2: n = 20, p = 7; study #3: n = 25, p = 7), empirical analysis shows that user segments instinctively choose only one and the same product variation as their most preferred one (see Fig. 5).

These consistent observations lead to the assumption that the semantic differentials representing users' attitudes and values also suit for product appearance studies. Based on this, we compared the different semantic differentials of the respective user segments and those of the varied product derivatives. In this analysis, we state that the most preferred product derivative in the respective user segment is also always the one that has the most similar impressions profile.

We therefore conclude that users choose those products that show most similarity to their own attitudes and values. Knowing this, we can assume that with the ability to design products showing similar impressions profiles as the target users do, we will be able to better address their subjective requirements (Fig. 6).

4 Statistical Evidence in Similarity Analysis and Automation

The evidence of users' preferences referring to the similarity of the users' and product's impressions profiles raises the question, how this similarity can be mathematically measured and valued to support the product designer (see Fig. 7). As this is a multi-dimensional phenomenon, similarity considerations are not trivial.

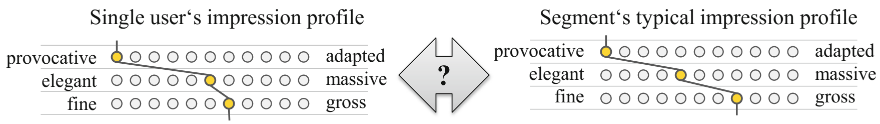

Fig. 7 Adequate similarity measurements are needed in comparisons of single user‘s (product’s) and segments’ profiles

Similarity has no general definition as it is highly dependent from its respective context. However, in mathematical analysis similarity can be represented by a function that measures the grade of congruency of objects in intervals from 0 (no similarity) to 1 (identical). Therefore distance measurements are often used [15].

In the case of profile similarity, we investigated six geometric distance measurement procedures that appear to be suitable for interval data (see Table 1). While five of these refer to absolute distances between two item variations, one of it focuses on angular differences in between 2 × 2 items.

By applying these to the profile similarity problem, all five distance measurements were more or less adequate to identify similarity. We distinguish two types of distance measurements. The weak ones (Table 1, grey) only show small differences between the compared profiles, whereas the strong ones show higher variations that simplify interpretations. The cosine distance measurement is based on angular similarity observations and was nevertheless added due to the case illustrated in Fig. 8. There, two extrema in similarity are shown. Whereas the example on the left is reliably detected by distance measurements, a basic shift of the profile to one side of the compared is not detected.

In a first try, the cosine similarity investigation showed no additional findings. Reasons for this originate in both context and mathematical circumstances. First of all, the impressions profiles are based on user statements that allocate his or her personal feelings on a scale between one word pairing. This intends that a later shift on this scale would severely distort the user’s statement. Secondly, the arrangement of the impressions profiles does not follow up a strict order, even if this could be preserved in all studies. The absolute distances would stay the same in

Table 1 Similarity measurements based on distance and angular variations, *strong* measurements underlined [15]

Euklidic distance	$\sqrt{\sum (\boldsymbol{X}_i - \boldsymbol{Y}_i)^2}$	Bloc distance	$\sum \lvert \boldsymbol{X}_i - \boldsymbol{Y}_i \rvert$
Squared Euklidic distance	$\sum (X_i - Y_i)^2$	Minkowski distance	$\sqrt[p]{\sum (X_i - Y_i)^p}$
Tschebyscheff distance	$\max_i \lvert X_i - Y_i \rvert$	Cosine distance (angular)	$\frac{\sum (X_i \cdot Y_i)}{\sqrt{\sum X_i^2 \cdot \sum Y_i^2}}$

miscellaneous orders whereas the angular differences would not. Assuming that the order stays the same, there still is a difference between two angular differences depending on their reference values (Fig. 9). Knowing this and by adding a standardization step into the cosine similarity measurement, the output also shows adequate results like distance measurements. Nevertheless, this method was valued to be of minor interest due to the first arguments but is introduced as a further validation.

The procedure of an automated user allocation into the right segment is just the first step in a thorough user characterization based on socio-cultural investigations. We called this most similar segment the dominant one. Besides this, the user has up to five associative segments, depending on the dominant one. To sufficiently allocate the user within his or her dominant segment, we take two so-called associated segments into account. These are the ones that are second or third most similar. As the typical segment-related profiles are the more similar to each other as the segment themselves are in a distance manner, we can also use automated distance measurements here. Figure 10 illustrates those steps graphically. The final output is an automated user characterization in the socio-cultural milieus.

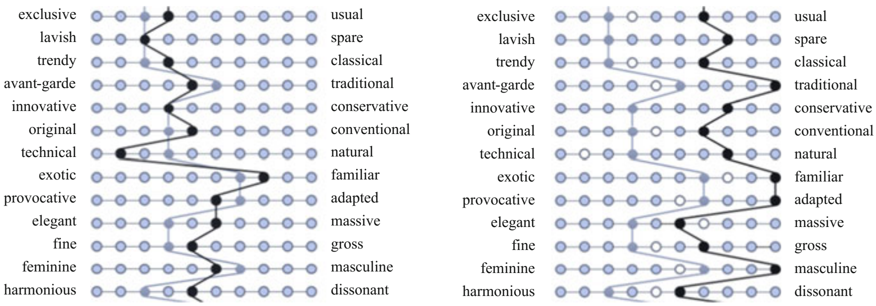

Fig. 8 Different types of similarity in profile comparisons (*black* single user, *blue* typology)

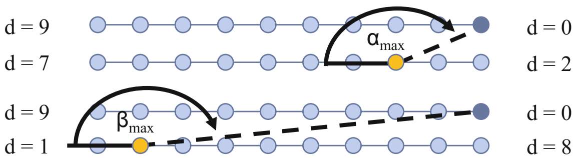

Fig. 9 Different angular extrema as basis for cosine similarity tests need intermediate standardization steps

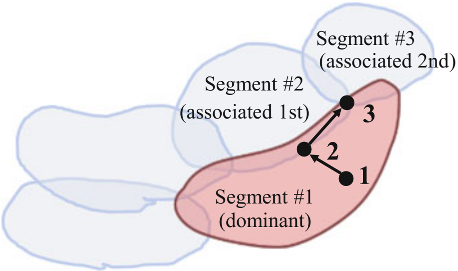

Fig. 10 Three steps to allocate single users in their respective socio-cultural segments by their impressions profiles using similaritiy measurements

5 Conclusion and Outlook

In the presented work, we assessed how to automatically allocate users in socio-cultural segmentations using similarity between single user's profile and the segment's typical profile. We showed that there are different types of similarity measurements that can be implemented to automate this allocation.

This leads to the conclusion that this procedure also helps to assess the preferred product derivative as it was shown that the users seek to look for products with the most similar impressions profile as their own. By knowing this, we can derive dependencies between different product characteristics variations and their effects on users' impressions. In Kansei Engineering, for instance, there are approaches how to do so using fuzzy logic or neural networks [16–18]. But there is no solution so far that links the users' preferences to this knowledge [19]. With the presented work, and with further studies in this field, we will be able to break down these insights to the properties of a product to directly adjust the product's design to the attitudes and values of the focused socio-cultural milieu (see Fig. 11). Therefore, we will expand our analysis set and increase the automation level by including

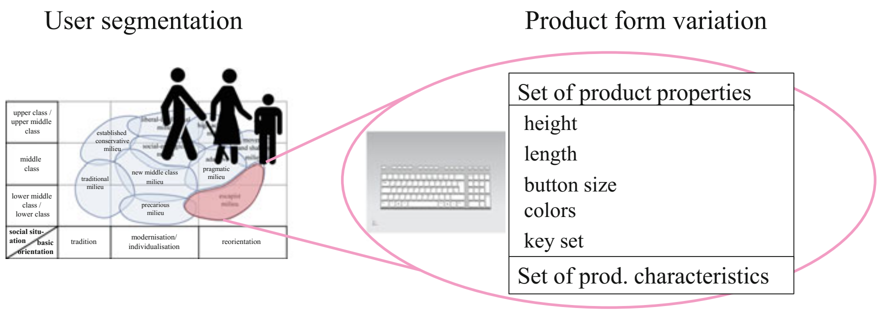

Fig. 11 Partial aspect of the ACADE procedure: adjusting the product characteristics to the user segment's preferences in the keyboard example

further data mining techniques (e.g. partly similarity checks in decision trees or multivariate analyses) [20].

In summary, we presented ACADE, an approach that links users‘attitudes and values to product characteristics and properties. It thus addresses long term subjective values that normally cannot be measured directly. Apart from a general user's impression measurement, it is shown that ACADE offers design optimization strategies for different socio-cultural segments. The consideration of socio-cultural backgrounds as a bundle of different important factors in the user's lifestyle is very important in marketing strategy and therefore for product development decisions. Apart from a better fulfilment of users' requirements and the resulting success for technical companies, it is also a societal question of the users' subjective needs and their quality of life.

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Hedonic Design. Contributing Factors in Generating Emotional Ties. The Shape as a Contributing Factor in Generating a Hedonic Design

Jorge Gil Tejeda and Lorena Olmos Pineda

Abstract One of the objectives we are pursuing is to create competition and innovation by creating competitive products with the aim of winning the praise of contemporary consumers. Thus, we are bounded to identify those factors that generate emotional ties with the consumer through an analysis of successful products as first step in the research and narrow interviews with university students according to INEGI (Estadísticas a propósito del día mundial de internet, 2016, [1]), in controlled environments. We are using the word *shape* as one of the most important factors; as one of first-impacts in the subject-object interaction process. Furthermore we propose that the material objects of a culture capable of generating emotional ties will be referred to as *hedonic design* indicating a difference in the way contemporary design is conceived (Gil in Paradigmas del diseño en la hiper-modernidad. 1er Foro de Diseño: Pedagogía y Conocimiento, 2014 [2]).

Keywords Hedonic design · Shape · Emotional ties · Emotions · Innovation

According to INEGI [1] "77.7 million people use a cellphone and two of each three users have a smartphone. 70.5 percent of Mexican cybernauts are under 35 years." In our case, we took advantage of that in the university's field where we have students ranging from 17 to 40 years old, which makes it a very viable resource according to the context.

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1 Introduction

It's a fact that the current dynamic has generated radical changes among consumers as well as within markets. We can observe the advent of a new kind of consumer that, from the demand point of view, has two qualities: they are selective and demand diversified products.

As far as users' urgency for products, a phenomenon of super segmentation of demand has emerged, requiring flexibility in the supply, in order to adapt to the needs of the diversified sectors with specific qualities [3].

Regarding the market we can identify the following qualities:

(a) Do major firm competitiveness understood as the skill owned by corporations to grow and develop their participation in the markets is related to those factors that generate emotional ties with the consumer?, as pointed out by Segura [4].
(b) From the supplier's point of view, do designers face the challenge of creating varied objects to generate competitive interdependence?, as pointed out by Hill and Jones [5].
(c) Do designers have to fulfill the purpose of creating a competitive advantage for the product during the process in order to analyze the qualities of an increasingly selective market sector?

2 Hypothesis

The type of hypothesis we are using is called research hypothesis in order to develop tentative explanations about possible links between at least two variables. We are analyzing 4 variables and their possible correlations, such as everyday objects for consumers, consumption versus quality of service, value and use time bonding, product preferences and relationship bonding, to find out which are the most commonly used objects in everyday life.

1. Do major firm competitiveness understood as the skill owned by corporations to grow and develop their participation in the markets is related to those factors that generate emotional ties with the consumer?
2. From the supplier's point of view, do designers face the challenge of creating varied objects to generate competitive interdependence?
3. We wonder: Do designers have to fulfill the purpose of creating a competitive advantage for the product during the process in order to analyze the qualities of an increasingly selective market sector?

3 Methodology

As for the experimental design we established research study four variables wherein each of said variable respond to a block of 60 questions. Therefore for the first part of the study questions we applied two blocks where each is 60 questions. With a total of 120 questions.

For the first part of the experimental design we applied two blocks of questions to 2 groups of 30 people, men and women in equal proportions aged 19–22 years. The total number of users interviewed in the first stage of the research is 60 consumer users.

For the second part of the study we applied three blocks of questions where each of them is 60 questions. With a total of 180 questions. For the second part of the experimental design applied three blocks of questions to 3 groups of 30, 28 and 22 people respectively, men and women in equal proportions aged 19–22 years. The total number of users interviewed in the second stage of the research is 80 consumer users.

Like any research process we are in a very primitive stage when the hedonic design a new methodological and theoretical field most likely technical foresight in terms of our research will have different steps to solve several hypotheses that establish progressively as advancing our research. For this first stage of research independent variables we determine not handle the complexity of the subject. We prefer to handle dependent variables so we made use of the camera Gesell where precisely control the dependent variables mentioned below:

1. Check application questionnaire
2. Lighting conditions
3. Temperature
4. Application time test
5. Analyzed products
6. Number of questions in the questionnaires applied

4 Context

In Mexico it is important to address international competitiveness in the context of Design, by means of innovation and generative research in the classroom. We aim to give a new vision to the university student on how to conceive of design in our contemporary era. Similarly we want to emphasize the difference between the hedonic design and current design.

5 Description

Our research includes theoretical support to better understand the concepts together with the analysis of successful cases in the area of design. The techniques employed to support the present study include conducting polls among students guided by our observations of consumer's behavior and related measures in a controlled environment.

5.1 Development

The discerning factors that improve a company's competitiveness could be divided in those areas related to the corporate and the intrinsic aspects of a product. According to Dubé and Renaghan, the enhancement of competitiveness can be seen by the viewpoint of internal improvements to the company itself. This impacts the consumer's perception of the service given [6]. For this reasons in this study a poll was carried out among consumers ranging from the ages of 19–22. We are analyzing 4 variables and their possible correlations, such as everyday objects for consumers, consumption versus quality of service, value and use time bonding, product preferences and relationship bonding, to find out which are the most commonly used objects in everyday life. Not necessarily successful projects 95% of a 60 student sample assert that their closest everyday object is their cell phone. Furthermore 3% of the 60 student sample assert that their closest everyday object is their car while 2% prefer their tablet. Regarding the question of problems in company services, 98% commented that they would buy the most updated version of their cell phone for those benefits that it offers minimizing the customer service given by the company. 2% answered consider the integration of product and service important. We can perceive that these benefits mentioned by the consumer are strong enough to generate loyalty towards a firm.

5.2 Creators of Affective Ties

When consumers look for a product they try to satisfy their preferences in line with hedonism as a theory of welfare [7]. This theory recognizes that a need must be identified. However not all the products that satisfy our needs are capable of creating close ties with the consumers.

We begin this analysis by designating two basic qualities of the product: those related to the function and those referring to its physical characteristics. Zeithaml maintains that the consumer is particularly attracted by the physical nature of the object and also to the pleasure that the object can bring him or her [8].

Other research has analyzed the impact of a product through the proportionate function and the fulfillment of this function by developing a classification of products that accomplish or exceed hedonic desires of the consumer. The authors explain that hedonic desires are satisfied through the hedonic benefits offered by an object. They illustrate that by using this concept they refer to the aesthetics of an item, and they explain that the appraisal of similar benefits is the result of an experience with the product [9].

We highlight three sequential fundamental stages once a necessity has been established; the first is the identification of the object via its physical characteristics and here is where aesthetic and symbolic values come in play. The second is the first interaction with the item where an evaluation of it is generated at a functional level. The third is the acquisition of the product where it is intimately known and ties are generated.

5.3 Subject-Object Interaction

In this paper we analyze some of the relationships of interaction between everyday life objects and consumers, conceiving of the interaction as a form of communication Table 1.

It can be observed initially that the objects generating closer ties are usually those with whom we interact more: this is the result of the major frequency of use becoming a major factor that generates ties. Starting from the definition of affection based on Zajonc, that defines it as a preference where the consumer knows the value he is bestowing upon the object [10], students were surveyed. Out of 80 students polled, 98% answered that tables they have in their houses do not inspire any emotional tie, and 2% answered that they have emotional ties with their tables because these are inherited from family members. 10% of the 80 polled answered

Table 1 Gil, J. Olmos, L

Object	Interaction level analysis
Table	Prompt interaction. There is not much physical contact. Occasions of major average interaction: breakfast 13.5 min. Lunch 27 min. Results of a survey of30 people. It is used by several people at the same time
Watch	Prompt interaction. There is physical contact. Occasions of major interaction: consulting watch 6 times per day. Providing multiple functions. Result of a survey of 30 people. Used by one person only
Car	Complex interaction. There is physical contact and communication. Occasions of major interaction: commute, Providing multiple functions. Result of a survey of 30 people. Generally used by several people
Cell Phone	Complex interaction. There is physical contact and communication. Occasions of major interaction: More than 17 h per day in different situations. Providing multiple functions. Result of a survey on = f 30 people. Generally only used by one person

that their watches are important to them as they were gifts from a loved one, even if they did not necessarily like the gift. 70% do not like to wear a watch because they don't need it so they do not have emotional ties to it. 20% like their watches but do not necessarily have an emotional tie to it. 98% of the 80 students answered that they have an emotional tie with their cell phones for several reasons: practicality, it keeps all their information including friend contacts, it allows them to see their agenda, they feel comfortable with it, they feel like in communication, they can listen to music, it provides entertainment, they are functional, among other reasons. With these results we can confirm that interactivity is a factor that can favor an affective tie with a device because of the additional benefits provided to the consumer and that, based on the responses obtained we can classify these as entertainment benefits or functional ones. It is also recognized here that the additional functional benefits are stronger—in the mind of the consumer—compared to those connected with entertainment, and that these specified functions generally have a common function of helping the user solve his or her problems: for this reason some additional functional benefits become what we call "ability expanders".

In order to substantiate this statement it is necessary to go back to the example of cell phones: a significant portion of the sample affirms in fact that consumers have an emotional tie to an object and a relevant interaction is generated, as compared to other objects of everyday life, due to those additional functional benefits offered. For this reason we conducted an exercise where 26 students were taught for 30 min the names of various authors and significant dates if their works. During this step important data was written on the blackboard. 72 h later students were asked about what they learned. It was observed that the students that took pictures of the blackboard notes with their cell phones answered more questions correctly and with more conviction. Those students that did not take pictures with their devices did not participate actively and demonstrated insecurity through their body language. This study demonstrates the importance of focusing on additional functional benefits such as improved learning. Likewise, we propose that this surplus does not reduce in any moment the primary function of the object, so they it won't create a negative response, as we are hereby demonstrating. Out of a 60 students 2% answered that they consider the integral service of the company important. When asked what they considered good service, they responded that call quality was important to them. We also discovered that they changed telephone providers due to the lack of good call quality. Nowadays we have to look for positive experiences generated by objects and companies to favor flow states. Csikszentmihalyi defines the flow experience as a complete implication of the actor with his own activity. They are highly positive experiences. The author considers the following key factors in this kind of experience to be significant: a situation of challenges, attention on the action, clear goals, feedback on one's action, a feeling of control and loss of reflective self-consciousness [11]. If we are conscious that we are not capable of solving problems, we will tend to give answers with uncertainty, a lack of satisfaction, unhappiness, and instability. Instability is a negative factor that can be connected to fear, a fundamental human feeling [12].

If an individual does not have a sufficient level of corporal dialogue while interacting with the object, since it is a factor of first impact, negative responses will occur instead of a status of flow: this is a topic of cognitive ergonomics where the shape turns into function.

The following are "connected factors in the creation of a hedonic design": a subject's needs, human skills, physical characteristics of the object, appraisal of the object, functional benefits, and the level of interactivity among others. The correct configuration of these factors can result in specific responses known as emotional responses (Frijda 1993). The more expressive the product the more likely this effect will be generated [13].

5.4 *Approximations in the Subject-Object-Emotion Relationship*

Chitturi [9] concludes in Delight by Design: The Role of Hedonic Versus Utilitarian Benefits, "The primary insights this research provides are as follows: (1) Products that meet or exceed customers' utilitarian needs and fulfill prevention goals enhance customer satisfaction (e.g., a car with antilock brakes and vehicle stability assist), and (2) products that meet or exceed customers' hedonic wants and fulfill promotion goals enhance customer delight (e.g., a car with panoramic sunroof and six speaker audio system)". Specifically, the authors propose that if utilitarian expectation is surpassed a satisfactory response is obtained, and while surpassing the hedonic expectation, delight is evoked. In the opposite scenario, when no utilitarian function is satisfied, responses like rage are provoked and the lack of satisfaction of an hedonic expectation evokes disappointment [9]. The authors argue in these studies that consumers place more importance on the hedonic benefits than on the utilitarian benefits. Nonetheless, they remark that this happens after the user identifies a function of the object. Moreover, Kivetz [14] explains that "consumers give greater weight to utilitarian benefits before the hedonic benefits, unless the consumer thinks he or she has earned the right to enjoy the product" [14]. Our premise is that aesthetic factors and utilitarian factors do not compete as they are not located on the same level of action in the perceptual activity and in interaction with the subject. For us it forms part of a sequential process we have explained in the preceding paragraphs. What is important to recognizes that different levels of stimuli exist, but not all of them evoke emotional responses.

5.5 *Stimulus Intensity*

It is well known that human beings have basic needs that must be met. In "The information theory of emotion" Sininov describes the relationship between the needs of human beings and the emotional response. He states that if an individual had no needs, no emotional responses would occur [15].

Eric Kandel, 2000 Nobel Prize winner in Medicine, mentions that in major part isolated stimuli can endure for several minutes. This phenomenon is known as short-term sensitization. Still, there are responses to stimuli that endure days or even weeks and are generally evoked multiple stimuli. This phenomenon is known as a long-term sensitization [16].

Leventhal suggests that each emotion is formed by several components and these are based on the activation of various processes. As a person increases his or her own experience throughout his or her life these generate two kinds of emotional processes: the schematic and the conceptual. Schematic processing is triggered by a mechanism of conditioning in which the conceptual processing of the emotion is based on the knowledge that a person is employing and that allows him or her to raise awareness on such emotions [17]. Being that the comprehension of an object is an intense stimulus—and as a result, longer lasting as compared to those objects that are not understood—we can affirm that the symbolic appraisal of an item is fundamental to its functional perception.

5.6 Information Consumption

Information consumption can be interpreted as a complex socio-cultural phenomenon that takes place in our modern age.

Strongman, in his theory of information establishes a relationship between emotion and the need for information. He affirms that, if the information is not sufficient for a person, his neuronal mechanisms lead to a negative response. In other words, they result in a lack of satisfaction [18].

In his theory of personality; Jung describes the attitudes and basic functions of a person. These factors can refer to the way in which the subject obtains and processes information, for example classifying information according to his or/her characteristics in an intuitive manner, rationally or emotionally [19]. In other words, the consumption of information can also generate emotional responses.

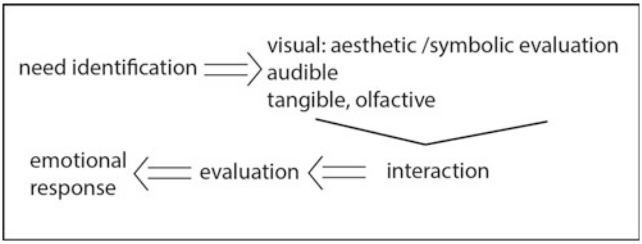
We assert that information provided by an object has to facilitate interaction and comprehension.

Based on what is affirmed here and supported by Pierce's theories, we consider it worth mentioning that several successful brands employ shape in their products with a clear relationship to its reference object. For example, several Alessi® items are iconic in nature. Apple® items, even if they use pure geometric shapes, suggest indicative signs through the use of materials, textures, and temperature, which express and manifest concepts of technology, innovation, elegance among others.

5.7 Appraisal and Appreciation of an Object

There are two models for testing the qualities of products. The first one is based on the perception of satisfaction that the product gives a consumer. The second one is based on the concept of normalized quality [20]. In the first model we can observe what happens according to perceived satisfaction. This perception can only take place with the interaction of the object and knowledge of the object itself. The second model depends on the standardized rules applicable to the company and market. Jung illustrates in a very simple way how subjects create judgements about the world around them: through thoughts and feelings, that is to say, we can judge facts as good, bad, or pleasant. In other words, feelings allow for the evaluation of a fact [19]. In the same way, Arnold affirms that any factor a subject faces is evaluated and estimated automatically by the brain. His study reveals that without an appraisal the generation of feeling is not possible. He maintains that in order to have a feeling the stimulus has to be evaluated as something that affects the person in some way [21].

Let's consider that, on the basis of our analysis, interaction manifests itself in the following way:



We considered, during the evaluation of the object in the first sequential stage of identification that first impact factors intervene. For example the manufacturing and physical qualities described in the functionality of the aesthetics of a product are the first ones that the subject encounters. As second impact factors we can cite indicative functions, object interactions and the ability to personalize. For us it is obvious that the factors belonging to this second group are perceived more and more during a process of progressive acquaintance with the object. Thus the post-sale experience becomes transcendental and the post consumption experience forms a third stage where the meaning of the items merge with it, integrating its symbolic functions.

It is important to take into account the fact that first contact factors involved in the perception of an object can appear altered by peculiar conditions of the subject. Palmero mentions that the appraisal done by a subject can be affected by his or her own intrinsic factors as his or her conditions, such as balance, and stability [22]. Likewise, Zajonc affirms that emotional variables such as the state of mind of a person seem to have a very strong influence on cognitive processes and thus on assessments [10]. A person is not an isolated entity but a social one, and for this reason rules and changes operate upon him or her. This change affects the perception of the object.

5.8 Subject-Object-Social-Integration Relationship

Casas makes an important contribution with this concept of "social welfare" [23]. Social welfare can be defined as an assessment we perform on the circumstances and functionalities inside society [24]. Its components, according to Keyes, are: social integration, social acceptance, social contribution, social renewal, and social coherence. Happiness subsists in the exercise of the highest human faculties, connected with the sense of success [7].

Therefore we can affirm that the qualities of objects of hedonic design can generate social welfare and contribute to the security of an individual in his or her social development.

6 Results

The fundamental factors in the hedonic design involved in the entire process were identified as: aesthetics and symbolism of the item, allowing the identification of the object in a context; initial interaction with the object, where a first level of function-need relationship is evaluated; an appropriate interaction by means of communication with the item and a first contact with the additional benefits of the function.

To prove this, an analysis was carried out in a Gesell Chamber based on consumer where no need for an object exists. 30 people were selected among university students and professors of different majors. They were put in a room without the need of a table. They were introduced and given the opportunity to choose individually between two items with equal functions but different aesthetic characteristics such as shape and color. 77.7% chose a peculiarly shaped table. 22.2% chose the table with traditional design. The average time it took them to pick an object was 3.7 s. Only 13.3% gave comments concerning the functionality of the object. 86.7% of the people without a specific need chose an item without evaluating the function, and chose it just for its aesthetic appeal. When their choices were based on information processing according to Jung based on emotional reasons their responses did not take more than three seconds on average. By comparison, those that analyzed the information took more than six seconds.

The second case analyzed involved two objects with different qualities: the first offered multiple functions while the second one offered precise function. Users' preference was towards the item offering multiple functions. To prove it the following analysis was performed in a Gesell Chamber, based on consumers' behavior where there was a lack of need. 30 people were selected among university students and professors of different majors. They were put in a room without a need of a table and a cellular phone. 66.6% chose the object with additional functions while 33.3% chose the object with one precise function. The 33.3% took 2.8 s to evaluate the object. The highest percentage of people without a need of both objects chose one item for the extra function it offered. Their choices were based on information processing, according to Jung, in a rational way. The interesting aspect is that if a consumer realizes the extra benefits of an item through conscious evaluation, his or her response is short and confident.

The third case analyzed consumers' choice between two cell phone brands offering multiple functions and similar aesthetic appeal. Users had a need for these items as their own cell phones, were out of date. Most of them chose those models they thought offered better functionality. An analysis was conducted in a Gesell Chamber, and was based on consumers' behavior in presence of a need for an object. 30 people were selected among university students of different majors. They were all in the market for a new cell phone. 71.4% chose the cell phone they considered more resourceful, compatible with more free applications, and that was perceived as more rewarding. They took an average of four seconds to make their choice. 28.5% chose a cell phone for its aesthetic qualities and for the popularity of the brand. 48% affirmed having problems in understanding interaction with one of the brands and for that reason they preferred the brand they already knew. 14.3% gave commentaries concerning the attractiveness of the icons used by one brand compared to the other, and there were also references to phones' symbolic level. Here we can see a choice based on information processing, according to Jung, on a rational level even though their answers did not take more than four seconds on average. On the other side were those that analyzed the aesthetic of the item longer, approximately 8.3 s, as they were already conscious that the functions of the phones were very similar.

Problems in these analyses include the fact that the items were not presented in a real scenario such as a department store, where more visual competitiveness and distractions exist: here consumers were in an isolated and controlled environment.

7 Conclusions

Consumers have to be recognized as people with emotions. Evaluation responses before some items are based on those information processes that are determined by the existence of a need or the absence of the same need. Responses given by consumers without the need for an object are based on aesthetic qualities—symbolic items, before functional. Their information process is faster as there is no deep analysis. Even if the perception of the object post-consumption, can lead to changes in the item interacting with it for a long period of time. Nevertheless if the object Functions adequately, positive responses and brand positioning are generated.

Probable responses were given by consumers with a need of an object according to functional qualities rather than aesthetic ones. The information processes take longer time as a deeper analysis is required for decision making. The post-consumption perception can change for malfunctioning once the item is known. Yet if the object counts on adequate functioning much more positive reactions and brand positioning are generated.

Therefore, items of a hedonic nature should have excellent aesthetic and symbolic qualities in order to allow stronger interactions with consumers by means of possible personalizations, and the opportunity to give extra benefits and an adequate control of its figurative level.

Items nowadays should not be seen as manufactured products offering only one precise function but as objects offering solutions to different problems. The paradigmatic definition of Hedonism that should be strongly considered in our society is that of a *Process, resulting from the correct relationship among associated factors.*

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Visual Design Considerations for Evoking an Emotional Response Towards Non-personalized Information to Encourage Object Loyalty Amongst Users

Priyanka Bharti

Abstract Health card is issued to a child immediately after his/her birth, in any medical system; private or government. It is the only channel to maintain the records of the vaccinations and health related concerns of a child, ageing 16–18 years. But in immense cases it has been found that they go missing once a child ages 5/6 years, reason; they find it trivial for future benefits. Hence, comparative study was undertaken to understand the reasons behind the trivial perspective of the users. Linchpins were extracted from the study which is efficiently required to engender a personal response towards the health card, under Indian context.

Keywords Health card · Health · Vaccination · Immunization · Emotional design

1 Introduction

Public Health care services in India are delivered through a well-established network of health care centers at state levels funded by the government of India. But, on the grounds of studies and researches it has been clearly stated that health issues related to urban health issues varies on immense parameters with rural health issues [1]. In rural areas, Primary Health Centre (PHCs)/Community Health Centers (CHCs) are responsible for providing basic health services related to Antenatal care and immunization to citizens who may not have regular access to medical facilities [2, 3]. In Urban areas, Urban Health Centre (UHCs)/Community Health Centers (CHCs) provide the same service. These health care activities are carried out by frontline health workers namely ANM (Auxiliary Nurse Midwife), ASHA (Accredited Social Health Activist) and AWW (Anganwadi Worker) at the community level. These field workers travel through the communities dispensing health

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care solutions and form the crucial back bone of India's health care delivery mechanism. ASHA is a responsible body for the immunization services and absolute neutrophil count (ANC; the number of white blood cells (WBCs) called as neutrophils) for the newborn and expectant mother of the dedicated area [3].

Immunization is the process whereby a person is made immune or resistant to an infectious disease, typically by the authority of a vaccine. Vaccines vitalize the body's own immune system to protect the person against subsequent infection or disease which may be life-threatening which contributes in successfully averting 2–3 million (approx.) deaths per year [4]. Immunization/Health Record Card is an extensive tangible paper/hardboard card/record copy/note for introducing details related to childs' personal information, family and relatives data, diseases he/she suffered from/had a symptoms of and other health related issues like growth, vaccinations, treatments, medications, allergies, etc. This card has been issued to each and every newborn child's parents on compulsory basis by the health centers in order to keep the record of a child vaccines and health related issues.

2 Preparation of Your Paper

Public and private sector clinics/health care center has their own customized designed immunization card for the child when vaccines were administered. These cards has few commonalities on the grounds of information's like vaccination table, with due dates and given dates of the vaccination with graphs related to weight (girls and boys separately), circumference of the head and height of the child (girls and boys separately) till 36 months of the normal child growth, but varies at their portrayal level. All these information are sometimes comprehendible to the parent while sometimes it goes missing because of various aspects:

i. **Literacy**—Immunization record card in general prints its instructions in english (in order to keep it universal) which becomes a major issue for an ill-literate and low literate users. Other parts/states of the India also use their vernacular language (as per state) text for the instruction (mostly found in government health clinics) in order to facilitate effective comprehension of the card and its instructions but literacy remains the major challenge.

ii. **Personal perception**—Ill and low literate (major population of India) users and sometimes even literate users blindly rely on the medical health care taker (hospital staffs) for the vaccines and doses necessary for child's immunization. They hardly investigate for some extra information about the vaccine or side/ill effects of the vaccine. And, so they believe that the card comprehension belongs to the medical health care taker not to them personally, as they are the expertise. Users in general just follow the instructions verbally dictated by the health care taker. Moreover, the vaccines name with technical names like BCG, OPV etc. makes it more obvious for the parents to keep them away.

iii. **Legibility**—As per the hierarchy of the information, vaccine injections and doses w.r.t. duration are at prime level but the representation hinders the legibility. Use of abbreviation and vast graphs with microscopic details add on to the cognitive load of the users, which contributes in low legibility. Lack of design element framework, legibility becomes an unavoidable issue with the immunization/health record card. Also, manual data entry of due dates and date of vaccination aid confusion.

iv. **Irrelevant information**—Card is populated with extra information due to which it becomes impossible for a user to distinguish between the important and less important information in the card.

2.1 Research Question

Immunization card is also popularly known as health record card but it fails to justify its name. Above mentioned points clearly states the reason why users are unable to understand the importance of the card and where do the card takes away the facility of comprehension in effective manner. Until and unless a motivation/value/emotional or personal connection are involved to a thing, it becomes very difficult for a human to save it for future. So, what are the elements required to be integrated in the present health card that it will facilitate evoking of emotional response towards the non-personalized information to encourage loyalty among the users.

3 Methodology

The study was conducted in the cities like Kanpur (U.P), Bokaro(Jharkhand), Ludhiana (Punjab) and Chennai (Tamil Nadu). Methods of sampling were randomly strategized under which the hospitals were initially categorized broadly as government and private. In the first stage, government set up was undertaken and for the second stage, two different types of organization were taken under the study which was strategically divided on the basis of their work role i.e. private hospitals and child specialist clinics.

Semi structured interviews were also the part of the data collection which included parents, hospital staffs and the doctors. Few nearby villages were also covered for the focus group discussions that included low literate users more.

4 Findings, Analysis and Proposed Solution

Health record card is printed by National Government and served for free to the child's family, by the respective organizations. Within most of the families (96% as per primary data) it has been found that they lose it or misplace it after a child attains the age of 5–6 years. Moreover, parents/family can hardly recall the list of vaccines their child received during their early age. As, the card is misplaced/goes missing, it becomes very crucial for a doctor to diagnosis a disease of a child at early age. Hence, it is very important to save the health record card for future health issues. It is also considered as one of the essential document during few travel trips, job, education etc. Following are the major aspects why most of the family loose it or misplaces it:

i. Awareness—Health card is an important document which can be used in future, hardly know by the users. This card was meant for child but the comprehension part was taken care by the medical health care taker so there is no attachment between card and parents (only responsible person for saving the health card for lifetime).
ii. Perception and beliefs—According to their previous generation experience they believe once the child is ready to walk, no more vaccinations are required as they believe after the age of 4–6 a child develops their strong immune system which is enough to fight against the foreign materials in the body. Hence, they lose/decompose the card after a child turns 5 or 6 years (if they have the card).
iii. Standard size—No standard size for the health card is followed yet in India. It varies from A5 (double to triple fold) to A4 (double or triple fold) or some customized arbitrary size.
iv. Omitted role for parents—Almost all the health card follows same tabular form to mention the vaccination dates and doses. Demographic details are followed by the first page and the tables with the next page. As the details are entered by the medical health care taker, parent's views are insanely neglected. So, the parents are only left with the task related to health record is to carry it along during vaccines. Users find it difficult to comprehend due to which they lack in making any emotional attachment.
v. Chunking of space for data entry—There is no enough space to enter the vaccination dates and due dates in the table present in the card. Staff members are responsible for entering the data. Most of the time in utter rush the hand written data crosses the boundary line of a particular segment and ends up in the next row/column. Results, most of the time confusion occurs for the next due date and doses of the vaccinations.
vi. Customization and persistence of the card—Health card is printed on the hard paper without lamination or on binding paper with/without glossy finish that is definitely not long lasting. Almost every woman has small purse/wallet to carry their cash/coins. Each of them uses the same purse to keep the health card, while travelling to the hospital/health care centers with

their child. Hence, card cannot resist the folds and ends up either by having numerous cracks and gets torn into pieces, after a certain number of usages.

vii. Visual solitary ambiance—As compare to other important documents, health card do not carry any unique feature (visually) that can actually drive user to keep it safe for near future. It is hard to stand out in the surrounding.

viii. Lack of personal belonging-ness—Served free to the child parents, they lose to understand the importance of the card.

ix. Literate information for low literate users—Health card consist of textual information with few pictorial information (optional). It becomes bit difficult to concentrate at a point to seek any particular information as chunking and hierarchy of information is not well planned. E.g. all the list of vaccinations are placed under one table which makes it difficult to read after few entries; done by the health care workers/staff.

An attempt is taken to justifying the name "Health Card" by proposing following changes:

i. Standard size—Existing health cards have different sizes and shapes. As per the proposed design, a standard size for the card is proposed i.e. passport size. Passport easily fits in shirt and pant pockets as well as in women wallets (not all but mostly). Users have already built a perception for this size of the document i.e. an important document, so on the same ground they will have the same perception for the health card i.e. an important document.

ii. Chunking of space for data entry—Present card has all the vaccination entry at one single page which might lead to the confusion because there is a conflict between the readability and understanding. Chunking of information is taken care by devoting two pages (seen at one instance) for every dose/vaccine/visit. One page consists of vaccines required during a visit for a child, specifying the instructions with info graphics and text (less), to reduce the readability issues with the low-literate and illiterate people. Similarly, the other page is devoted for the information that talks about the child's health, weight, circumference of head, eating habits, precautions and common seasonal diseases. This will help user in better understanding of the child's health and can help reducing their reliability on doctors and medical staffs for all sort of small information related to the child health. It will also act as an educational tool for the family.

iii. Visual solitary ambiance—Present health card is more or less looks like an ordinary document which can be blue coloured leather finished material with a seal on (logo of a UNICEF and WHO). This will add value to the card and user will feel connected to an esteemed organization, responsible for their child's health and growth (Fig. 1). This will motivate the care takers to keep it safe for the future usage (Fig. 2).

iv. Lack of personal belonging-ness—(Unique identifier that is intimately connected to the child) Vaccination is typically considered to be given till the age of 17 years, which is hardly attempted by any care takers. The main problem

Fig. 1 Proposed design 01—booklet size and cover

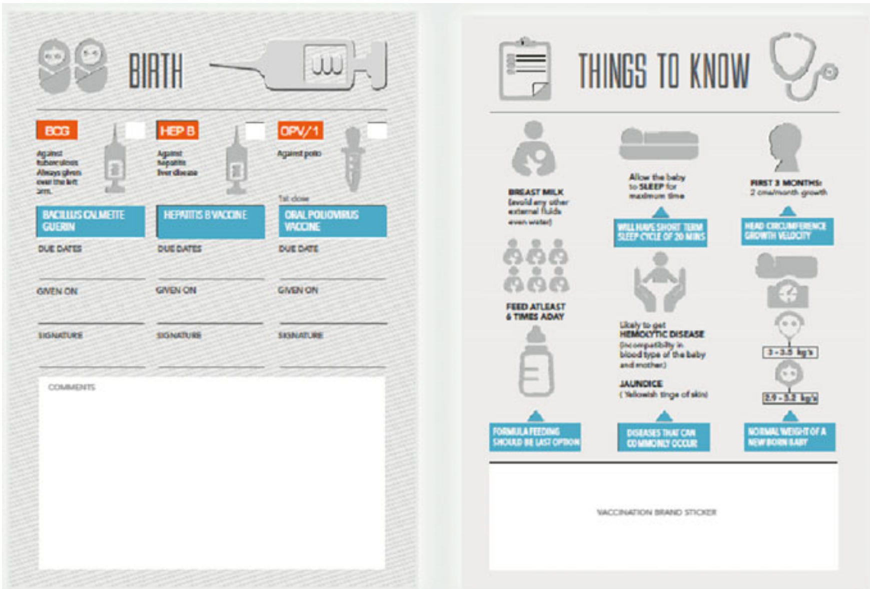

Fig. 2 Health booklet pages

behind this is the availability of a card that can contribute reminding them the vaccine due date. Incorporating birth certificate within the health

v. card is prosed, that will contribute in value addition to the document. Birth certificate is an important document for every individual and the booklet holding it can be easily preserved for the same. Assuming if the sticker can be placed in the first page of the booklet, stamped by the authority to declare it as a legal birth certificate for that individual then it itself adds a value to the booklet. Demographic description on the first page is also placed in a way so that digital entry can be easily performed (Fig. 3).

vi. Readability-legibility—Information present in the proposed design is a combination of info graphics and text. Low literate users commonly break the words and sentences while reading. So, to solve this problem we tried using simple words with very small sentences. Presence of info graphics will help them to understand the process quickly. It will also help illiterate users, too.

vii. Visual perception and color coding—Three sets of color are used in the proposed design: Orange, blue and grey as per their intensity. Text present on orange box contains the major importance which is further followed by blue and grey. Orange highlights the name of the vaccine; need to be given, blue shows the full form of the name of the vaccine and the things that should be known by the care takers for the betterment of a child's health and growth. Grey color do contains the information but of less priority that a care taker is supposed to know (Figs. 4 and 5).

Fig. 3 Birth certificate placed inside the booklet

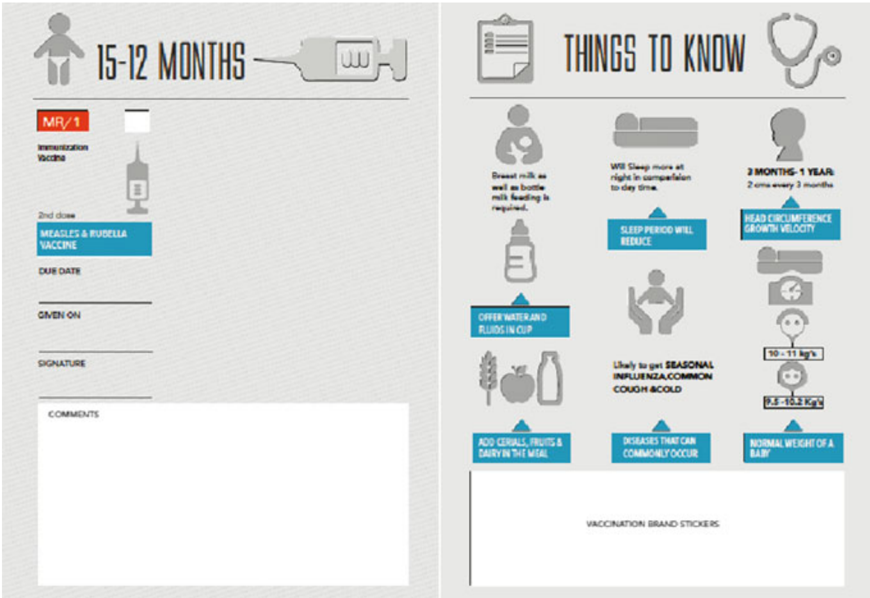

Fig. 4 Color coding for the information hierarchy

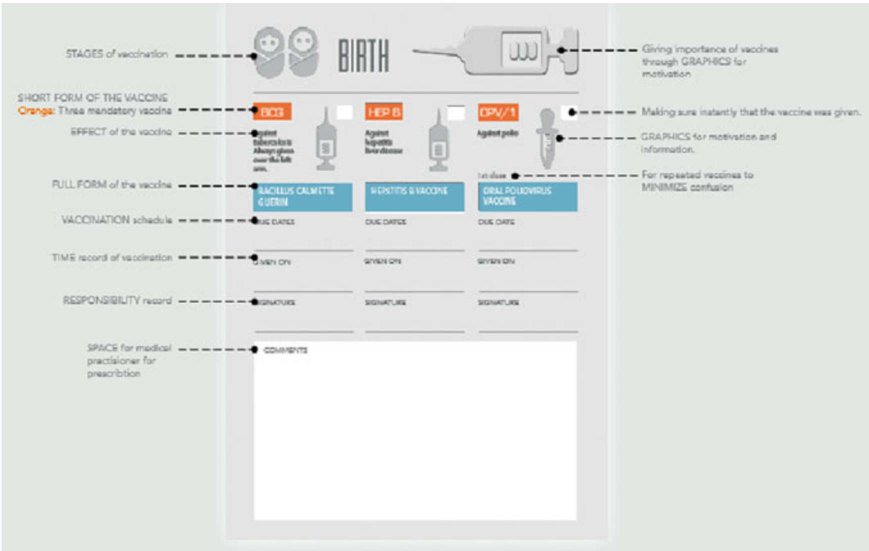

Fig. 5 Design—explanation

5 Scope of the Study

Comparative study was only conducted among the heath cards of north Indian states including Punjab, Delhi, Jharkhand, Uttar Pradesh and Bihar. And, only visual part has been taken care majorly of because language shapes up the perception and to cater various perceptions in a culturally diverse country like India will be a challenging task.

6 Discussion

Health card is a good way to preserve the health record of an individual but only if it is kept safe for future. A solution is proposed to strengthen and improvise the health card value by redesigning the card visual elements (primarily). It's not an optimal solution but a satisficing one.

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Preferences in Recall of Pleasant and Unpleasant Images

Mritunjay Kumar, Rajesh Ranjan, Braj Bhushan and Ahmed Sameer

Abstract The role of emotional state on memory has been well established. How emotion provoking stimuli influence the cognitive processes is, however, not well understood. Our broad objective was to see the impact of emotion provoking visual stimulus on memory. Sixty images were generated using Indian version of the Geneva Affective Picture Database (GAPED). Four categories of images (child, adult, animal and landscape) were either pleasant or unpleasant in nature. These images were shown to thirty participants following a repeated measure design. Immediate free recall of the images was recorded to see the effect of type of image on recall. Bayesian inference was used to analyze the data. Results show evidence for effect of type of image on recall by 120:1 against the null. The model of image category was also preferred to the null by 35:1.

Keywords Design aesthetics · Pleasant images · Unpleasant images · Recall · Visual design

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1 Introduction

Retrieval of past information is referred to as recall. Stimuli can be recalled either with a pointer to memory (cued recall) or without any cue (free recall). Emotion component of the stimulus affects the ease of recall [1], although the relationship between the nature of recall depends on the retrieval process involved (cued vs. free recall). The role of emotion in cognitive processes, such as memory, has been well documented in the area of behavioral sciences. Generally emotionally arousing stimulus tends to be more salient than non-emotional stimulus regardless of its valence (pleasantness or unpleasantness). This is probably the strongest explanation of enhancing effect of emotion in cognition. Large number of studies have been carried out to study this relationship and the results have mostly provided evidence for the effect of emotion on memory. For example, emotional pictures tend to be remembered more than non-emotional pictures [2]. Quite often this recall is more accurate and vividly than non-emotional events [3].

Emotions play a vital role when we interact with an object in our daily lives. Extension of our emotion is reflected the way we interact with the products and surroundings of our physical world. This emotional interaction has implications in various design disciplines like interior design, product design, architecture design, home appliances design, etc. Thus, designing a product which elicits emotional response is likely to impact the recall preference as compared to the neutral products. Various brand logos and books can be designed for better remembrance ultimately affecting the sale of the product.

Behavioral and neuroscience research have attributed better memory for emotional events to the interactions between the amygdala and specific brain areas [4]. This effect seems to present across modalities like sound [5], smell [6], vision (faces) [7], etc. In a classic study Jersild [8] found that memory (recall) of pleasant experiences was better than that of unpleasant experiences. Similar evidence has been obtained for other modalities. However, there has been lack of systematic comparison of effect of pleasant and unpleasant visual stimulus on subsequent recall. This study aimed at filling this gap. Our broad aim was to see the role of emotion provoking common images on memory. As stated above, many researchers have established that emotional stimulus across modalities would be better remembered than neutral stimulus. However, to the best of our knowledge, there is not enough evidence as to memory of an object, especially those that we encounter in our daily lives, with respect to the type of emotion it provokes. To answer this question we classified visual images as pleasant or unpleasant and compared their recall. We hypothesized that recall of pleasant pictures should be better than recall of unpleasant pictures.

A wide range of pictures or images are seen daily. Besides our natural habitat they appear in books, television, advertisements, etc. Sometimes these images become an important part of our functioning. For instance, while learning English

Fig. 1 English pre-school book image with the letter ‘C’

alphabets it is important for a child to remember images associated with a particular alphabet, say ‘C’ with the image of a cat. We choose images that would fall in broad categories from whatever we encounter in our day-to-day life. While real life experience forces us to see pleasant as well as unpleasant images/visuals, products such as childen book that we design give us the freedom to select images that could be either pleasant or unpleasant. Figures 1 and 2 respectively show the alphabet/ *vyanjana* and the corresponding images published in two different books for children. While these letter-image pairs have associated two different animals (cat and *Ajagar*/python) the designers and publishers of such books remain ignorant about the emotional valence of the image and its effect on memory. In all likelihood one of them might appear pleasant to the child while the other one might appear unpleasant.

With an intention to gauge the differential emotional valence of things largely available in our environment and the likelihood of these images being used as examples in textbooks for children, we selected four groups of images—child, adult, animal and landscape. Further, these image categories had pleasant, unpleasant as well as neutral images. We were interested in seeing which of the categories are remembered better than others. This brought us to our second objective that was to see the effect of category on subsequent recall. Neutral images were used only for comparing the effect of emotional valence.

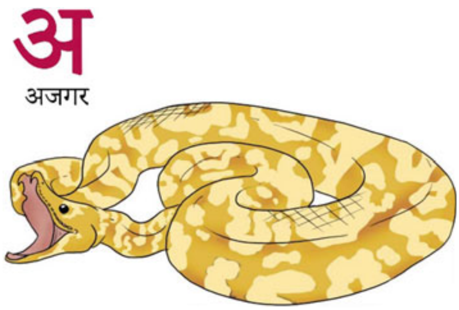

Fig. 2 *Ajagar*/python image in the Hindi pre-school book

2 Method

2.1 Participants

Thirty graduates, 22 males and 8 females, (Mean age = 26.7 years, SD = 4.5) from a technical institute voluntarily participated in the study. The participants were randomly selected from the pool of volunteers who gave their preference on the basis of call from the first author. Students of design discipline were excluded from the study to control for bias in visual aesthetics. Students' with any type of eye-defect were also excluded.

2.2 Materials

Test Stimuli The stimuli consisted of a pool of 60 images inspired from GAPED [9]. These pictures had similar attributes and were culturally salient to the Indian context. The reason for doing this was to avoid related issues because GAPED consists of images from a different cultural background. The images were classified on two parameters—type of emotion provoked (pleasant, unpleasant and neutral) and category (child, adult animal and landscape). All the images were formatted to maintain uniformity of width and height (640 $\times$ 480 pixels).

Rating of Images Participants' were shown the images on Tobii TX300 eye-tracking monitor and were required to rate them for the intensity of emotion it provoked using Self-assessment manikin method (SAM) [10].

3 Procedure

Participants were shown pleasant, unpleasant and neutral images on Tobii TX300 eye-tracking monitor at 1920 $\times$ 1080 resolution. Each images appeared on the screen for a period of 5000 ms and was followed by a response screen where the participants rated emotional intensity of the images. The participants were also instructed to remember as many images as possible for the upcoming recall task. They were provided with a blank sheet of paper and were instructed to write down the keywords or enough explanation which could explain the image even to an outsider. These images were further analyzed. Redundant information was excluded from the study. Total administration time per participant was 5 min.

4 Results

This study examined the recall preference of pleasant and unpleasant images. Table 1 shows the summary statistics of recall of pleasant, unpleasant and neutral images. As summarized in Table 1, unpleasant images had the highest recall. This was followed by pleasant images and then by the neutral images. The evidence of effect of images was obtained using Bayesian model comparison which produced a Bayes Factor of 120:1 against the null.

We also examined the recall preference for the content of the image. Figure 3 shows the mean for recall of each image category based on emotional valence of the images and the content. Table 2 summarizes Bayesian model comparison for both content and type of image. This analysis was run without including neutral images because they were not grouped into any category based on content. Analysis produced a Bayes Factor of 36:1 in favor of the model including effect of type of picture, its content and their interaction.

The findings suggest an interaction effect of emotional valence of the images and category (see Fig. 3). Generally, participants recalled better when presented with unpleasant pictures. However, for the landscape condition recall was better for pleasant images. As illustrated in Figs. 1 and 2, images of animals such as cat and python are used to help children learn alphabet-image association. In order to see which visual cues are actually looked at, we examined the heatmaps of selected images (see Figs. 4 and 5). The heatmaps make it very evident that not all visual

Table 1 Summary statistics for recall of images

	Neutral	Pleasant	Unpleasant
Mean	2	3.6	4.267
SD	1.875	2.298	2.741

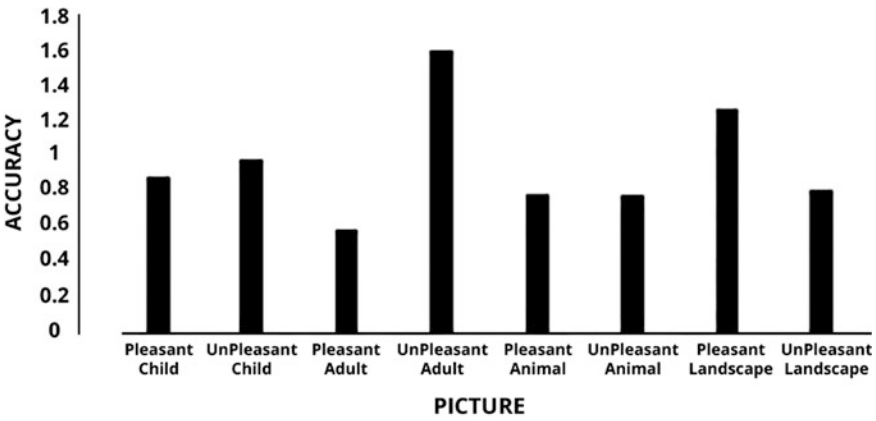

Fig. 3 Mean accuracy of participants' recall under all conditions

Table 2 Bayes factor model comparison for recall of images based on content and types

Models	P(M)	P(M|data)	BF_M	BF_{10}
Null model (incl. subject)	0.2	0.027	0.11	1
Picture	0.2	0.01	0.041	0.383
Category	0.2	0.004	0.014	0.131
Picture + category	0.2	0.001	0.005	0.047
Picture + category + picture × category	0.2	0.958	91.632	35.752

Fig. 4 Image of cat shown to participants and heatmap indicating the area looked upon by the participants

Fig. 5 Image of *Ajagar* (python) shown to participants and heatmap indicating the area looked upon by the participants

cues are attended by human beings and specific cues appearing pleasing or unpleasing are only attended to. Further, these cues helped the participants recall the images during memory test.

5 Discussion

Emotional stimuli tend to affect a number of cognitive processes. Recall (memory) of past/learned information is also affected by emotions. This is a well-established finding in psychology and is known by an umbrella term mood congruency effect. Thus, a material learned under influence of a physiological state will probably be better recalled if the person is in the same state. This effect has been shown across modalities and populations. Research, however, has not been well established about the type of physiological state (or emotion) and subsequent recall in a baseline (or neutral) state. Literature generally has not favored any mood over the other in terms of recall. This study aimed at understanding which type of emotional stimuli (pleasant or unpleasant) better aid recall for commonly encountered objects. There was no attempt to induce emotional arousal in the participants except showing the pictures.

Since unpleasant stimuli generally tend to be avoided we hypothesized that pleasant images would be recalled more than unpleasant images. Although we obtained positive evidence for the effect of type of emotion on subsequent recall, it was not in the same direction. Our data suggests that it is unpleasant images that tend to be recalled more than pleasant pictures, although both of them were better recalled than neutral images. This is in conformity with earlier findings that emotional stimulus is better remembered than neutral stimulus [2, 3]. A possible reason for this may be that unpleasant images tend to be more emotionally arousing because of fearful themes such as python. This greater arousal would have led to better remembering of these images. However, in our study we did not control for arousal as the primary aim was to distinguish between the emotional valence and recall. Future research must systematically manipulate the arousal produced by emotional stimuli and see its effect on subsequent recall.

An emotional stimulus cannot exist without content. Thus, the images used in our study were also classified according to four commonly occurring contents—child, adult, animal and landscape. The contents were modified to make them emotionally provoking either as pleasant or unpleasant. To see the effect of category we conducted a repeated measure Bayesian model comparison and found evidence for interactive effect picture valence and category. Findings generally indicate that pictures were better recalled when they were unpleasant. This trend, however, is not seen when considering animal and landscape pictures. In animal pictures there was almost no effect of emotional valence. For landscape content pleasant pictures were recalled more than unpleasant pictures.

Putting the results together we can conclude that emotion provoking pictures tends to be better remembered than neutral pictures. Effect of type of emotion is, however, not straightforward. It depends upon the content of the stimulus possibly by affecting the state of emotional arousal. Future work will have to take into account all three variables into consideration. Emotional arousal with a particular valence and content should be varied to see the effect on recall. These studies will require much more control and should also make use of psychophysiological markers of arousal.

6 Implication for Design

These findings nevertheless have certain important implications for design. It has been found that pleasing products work better and are easy to learn. Emotions aid in decision making [11]. Consider the symbolic designs made for safety purposes such as road safety design, emergency services, etc. Design of the shape and color in this context does affect individual's recall preference [12].

The findings of the present study can be considered while designing books or comic strip for the children textbooks. Rather than having a neutral (black and blue textbook) a designer can incorporate a storyline ultimately making the content more pleasing and sensible. Use of colors and doodles might help the children to retain the content for a longer period of time. However, one paradox can be the use of unpleasant images in the textbook for a better memory recall. The emotion of fear and anxiety leads to a better recall. However, a designer can induce unpleasant images to help children learn avoidable objects in the environment. For example, an image of a snake can not only be used to help the child remember letter-image association, it can simultaneously help the child learn the list of dangerous objects/creatures in the environment which one should also avoid. Such associations would serve safety and survival function as well.

In conclusion we may say that designers must consider a balance between the beauty and usability of the products they make. Besides them the emotional valence of the product should also be taken into account, especially the ones that serves safety/survival functions.

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Attributes and Emotions in Product Form Design: A Survey of Professional Industrial Designers

Santosh Jagtap

Abstract Consumer response to designed products has a significant effect on how products are interpreted, approached and used. Design of products is crucial in determining consumer response and product success. In the form design process, designers may attempt to elicit specific attributes or emotions through the visual appearance products. However, there is little or no knowledge about which attributes or emotions they frequently or rarely attempt to elicit. We carried out a survey with 55 professional industrial designers to identify the attributes and emotions that they attempt to elicit in shaping visual appearance of products. The results indicate that designers frequently or often attempt to elicit some specific attributes and emotions; whereas, they rarely or never attempt to elicit some attributes and emotions.

Keywords Attributes · Emotions · Intentions · Product aesthetics · Product form design · Consumer response · Industrial designers · Product styling

1 Introduction

The visual appearance of products plays a key role in the consumer perception and evaluation of product properties, and has an effect on how products are interpreted, approached and used [8]. Based on the visual appearance of a product, consumers or users make judgements about its (un)attractiveness, interpret its function and mode of use, and make association between its characteristics and their own identity [7, 13, 14, 21]. A product's visual appearance is thus a key determinant of consumer response and product success [2, 5].

The design of products is crucial in determining consumer response and product success [2]. In the design process, designers play an important role in formulating

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intended consumer response, and in generating and evaluating concepts to effectively communicate the intended response [16]. In the design process, designers may attempt to elicit attributes (e.g. high quality, modern, innovative, futuristic, etc.), emotions (e.g. joy, satisfaction, pride, hope, calm, etc.) and general intentions (e.g. 'comprehension' which is about communicating a product's function, 'recognition' which is about communicating a product's brand or tradition) through the visual appearance products.

Several research studies, from fields such as aesthetics, product design, psychology, and marketing, have been devoted to studying how consumers respond to products [1, 6, 23]. While design research is important in understanding and improving design practice and education [17, 18], design researchers have given little attention to the process of shaping visual appearance of products [8, 16], excepting some research studies (e.g. [20, 24, 27]). This limits our ability to develop tools and methods for improving current practice and education of the form design process.

While the form design process is important in shaping visual appearance products, there is little or no knowledge about which attributes, emotions, and general intentions designers frequently or rarely attempt to elicit in the form design process. This research aims to fill this gap in our knowledge about the form design process. To address this research aim, we conducted a questionnaire study with 55 professional industrial designers.

2 Research Methodology

We developed a questionnaire using 'Google Forms' to identify attributes, emotions and general intentions that designers may attempt to elicit in shaping products' visual appearance. The questions were iteratively formulated and refined, based on an extensive literature review, discussions with researchers and practicing designers, and a pilot study. The requirements about minimising the effort required by respondents and increasing the likelihood that they would complete the questionnaire were also taken into account.

Because this study focuses on the practice of industrial designers in eliciting attributes, emotions and other general intentions, in developing the questionnaire, we selected studies from the literature that investigated aspects of the form design process and perspectives of designers. For example, in the case of the question regarding general intentions that designers may attempt to elicit, we used the list of consumer responses identified by Crilly et al. [8], because this list is based on a number of interviews with practicing industrial designers. The list includes the eight general intentions: (1) comprehension (e.g. to support consumers in understanding how a product works), (2) attraction (e.g. to make products attractive to consumers), (3) identification (e.g. to make a product identifiable with the lifestyle of target consumers), (4) attention (e.g. drawing consumer attention to the product, for example, by designing it differently from competing products), (5) attribution

Table 1 Example of questionnaire. In designing visual appearance of products, do you intend to elicit the following attributes?

	Always	Often	Sometimes	Rarely	Never
High-quality	○	○	○	○	○
…	○	○	○	○	○

(e.g. to encourage attributes such as modern, feminine, etc.), (6) emotions (e.g. to elicit emotions such as joy, surprise, etc.), (7) action (e.g. to provoke consumers to purchase the product or to use it in a specific way), and (8) recognition (to design a product as coming from a particular country, brand, tradition, etc.). While these intentions are not mutually exclusive or collectively exhaustive, they represent a range of consumer responses mentioned by the interviewed designers [8].

In compiling the lists of attributes and emotions, findings from a large number of studies were used, e.g. [3, 4, 8–12, 15, 19, 22, 23, 25], etc. The lists of collected attributes and emotions were reduced through discussions with researchers and practicing designers, and a pilot study (e.g. by eliminating synonyms). It is common to have up to 100 words in such lists [26]; this study consisted of 71 attributes and 41 emotions. The pilot study identified that designers needed meanings of words in the lists. We therefore included meanings of the attributes and emotions, using the online Merriam-Webster dictionary. This ensured that all the respondents had a basic understanding of the attributes and emotions in the lists. In addition, the pilot study confirmed that the respondents were interpreting the questions as intended. Replies to the questions took the form of 5-point Likert scales, see Table 1 for an example. 55 professional designers from India participated in the survey. The next section presents the survey findings, which are discussed further in Sect. 4.

3 Findings

In total, 55 designers—44 males and 11 females—participated in the survey (see Table 2). While all the 55 designers answered questions about the general intentions, 52 answered questions about attributes and emotions. Thus, the findings, presented in this section, about the general intentions, and attributes and emotions correspond to the 55 and 52 designers, respectively.

Table 2 Overview of the professional designers' experience

Years of experience	Number of designers
Less than 5	13
Between 5 and 10	23
Between 11 and 15	15
Between 16 and 20	2
21 and above	2

3.1 Intentions

As can be seen in Fig. 1, the designers indicated comprehension as their most frequently elicited intention (M = 4.44, SD = 0.76), followed by attraction, identification, attention and attribution; all these 5 intentions were reported to be elicited in the range ‘always’ to ‘often’ (M = 4.07–4.44), on a scale 1–5, in which 1 means never and 5 means always. The intention reported to be least elicited was recognition (M = 3.53. SD = 1.12), as compared to other 7 intentions. The mean score of all 8 intentions is above 3 (M > 3), indicating that they were reported to be elicited at least ‘sometimes’.

One way repeated-measures ANOVA was computed to assess the designers’ reported elicitation frequency of different intentions. There was statistically significant difference between the elicitation frequency of different intentions [$F(7, 378) = 8.424$, $p < 0.001$, $\eta_p^2 = 0.135$. The assumption of sphericity was not violated: $\chi^2(27) = 37.429$, $p > 0.05$]. To follow up these significant effects, we used Bonferroni post hoc tests, which showed that the intentions comprehension and attraction were reported to be elicited significantly more than recognition and action ($p < 0.05$). The intention recognition was found to be least elicited, compared to the five intentions—comprehension, attraction, identification, attention and attribution ($p < 0.05$).

3.2 Attributes

The 11 attributes, namely, high-quality, modern, innovative, reliable, practical, harmonious, elegant, convenience, beautiful, simple, and honest, received mean score of above 4, on a scale from 1—never to 5—always, indicating their always-to-often frequency (see Fig. 2). In terms of the designers’ reported elicitation frequency, we call this set of 11 attributes ‘high frequency’ set. The 30 attributes, hi-tech to provocative (see Fig. 2), received mean frequency score between 3 and 4, i.e. often to sometimes. We call this set of 30 attributes ‘medium frequency’

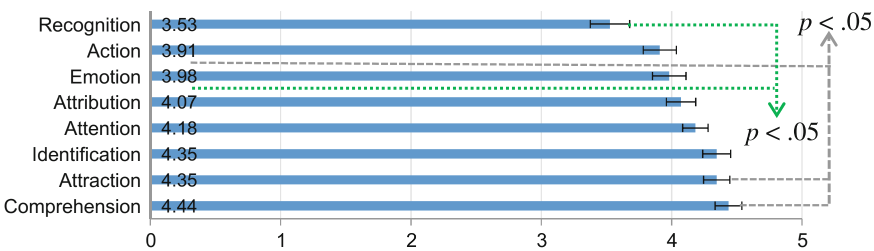

Fig. 1 The designers’ elicitation frequency of different intentions, with standard error of means indicated (Scale: 1—never, 2—rarely, 3—sometimes, 4—often, 5—always)

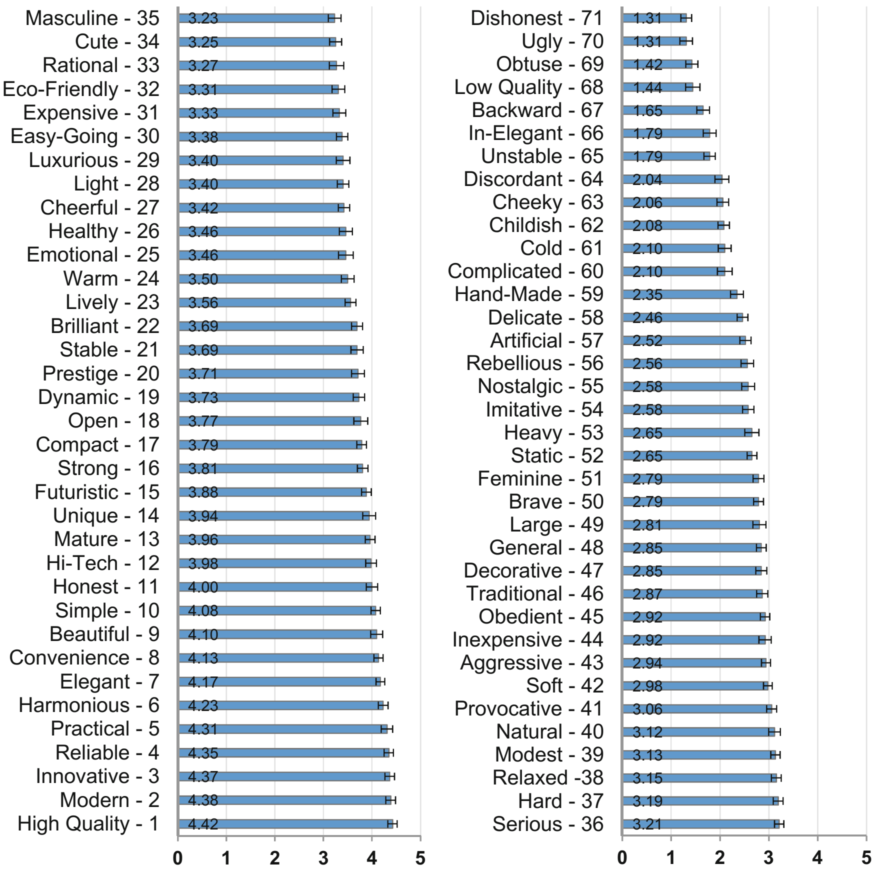

Fig. 2 The designers' elicitation frequency of different attributes, with standard error of means indicated (Scale: 1—never, 2—rarely, 3—sometimes, 4—often, 5—always)

set. Similarly, 23 attributes (soft to discordant, see Fig. 2), received mean score between 2 and 3, i.e. sometimes-to-rarely. We call this set of 23 attributes 'low frequency' set. Seven attributes, namely, unstable, in-elegant, backward, low-quality, obtuse, ugly and dishonest, received mean score between 1 and 2, i.e. rarely to never. We call this set of seven attributes 'least frequency' set. Table 3 summarizes the above findings.

One way repeated-measures ANOVA was computed to assess the designers' reported elicitation frequency of different attributes. There was a statistically significant effect on how frequently designers elicit different attributes [$F(20.211, 1030.753) = 49.961$, $p < 0.001$, $\eta_p^2 = 0.495$], with Greenhouse-Geisser correction. Post hoc tests with Bonferroni correction indicated that the attributes high-quality (elicited more often than 52 other attributes from the list of 71 attributes, $p < 0.05$), modern (elicited more often than 55 other attributes, $p < 0.05$), innovative (elicited

Table 3 Sets of attributes (the number of attributes in a set is included in brackets)

Set of attributes	Attributes
High frequency (11) (always to often)	High-quality, modern, innovative, reliable, practical, harmonious, elegant, convenience, beautiful, simple, and honest
Medium frequency (30) (often to sometimes)	Hi-tech, mature, unique, futuristic, strong, compact, open, dynamic, prestige, stable, brilliant, lively, warm, emotional, healthy, cheerful, light, luxurious, easy-going, expensive, eco-friendly, rational, cute, masculine, serious, hard, relaxed, modest, natural, provocative
Low frequency (23) (sometimes to rarely)	Soft, aggressive, inexpensive, obedient, traditional, decorative, general, large, brave, feminine, static, heavy, imitative, nostalgic, rebellious, artificial, delicate, hand-made, complicated, cold, childish, cheeky, discordant
Least frequency (7) (rarely to never)	Unstable, in-elegant, backward, low-quality, obtuse, ugly, dishonest

more often than 50 other attributes, $p < 0.05$), and reliable (elicited more often than 52 attributes, $p < 0.05$) were reported to be elicited most frequently. The attributes least elicited, as reported by the designers, are dishonest and ugly (both are least elicited as compared to 64 other attributes, $p < 0.05$).

3.3 Emotions

Of the 41 emotions, 20 (e.g. joy, satisfaction, pride, etc.) received mean score between 3 and 4, on a scale from 1—never to 5—always, indicating their often-to-sometimes elicitation frequency (see Fig. 3). We call this set of 20 emotions a 'medium frequency' set. The mean score of the seven emotions, namely, dreaminess, courage, kindness, sympathy, worship, lust and alarm, on a scale from 1—never to 5—always, is between 2 and 3, suggesting their sometimes-to-rarely elicitation frequency. We call this set of seven attributes a 'low frequency' set. The remaining 14 emotions, e.g. jealousy, isolation, anxiety, etc., received a mean score in the range 1–2, suggesting their reported elicitation frequency from rarely to never. We call this set of 14 emotions a 'least frequency' set. The above findings are summarised in Table 4.

A repeated measures ANOVA with a Greenhouse-Geisser correction showed that there was a significant effect on how frequently the designers reported eliciting 41 emotions [$F(9.436, 481.238) = 67.315$, $p < 0.001$, $\eta_p^2 = 0.569$), with Greenhouse-Geisser correction, as assumption of sphericity was violated: $\chi^2(819) = 1594.523$, $p < 0.05$]. Post hoc tests with Bonferroni correction indicated that the emotions - joy, satisfaction, pride, interest, and confidence—were reported to be elicited most frequently (joy elicited more often than 25 other emotions, $p < 0.05$; and each of the emotions—satisfaction, pride, interest, and confidence—elicited more often than 23

Fig. 3 The designers' elicitation frequency of different emotions, with standard error of means indicated (Scale: 1— never, 2—rarely, 3—sometimes, 4—often, 5—always)

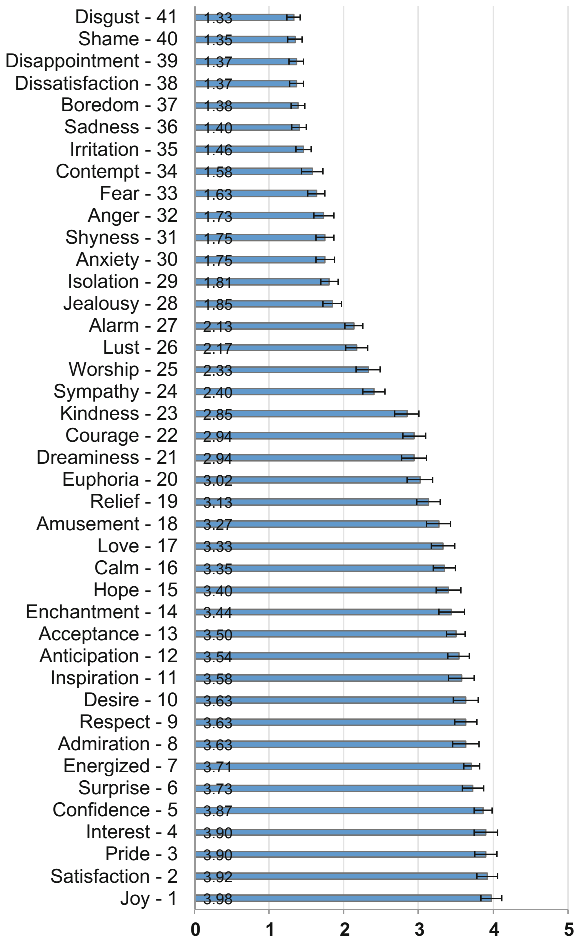

Table 4 Sets of emotions (the number of emotions in a set is included in brackets)

Sets of emotions	Emotions
Medium frequency (20) (often to sometimes)	Joy, satisfaction, pride, interest, confidence, surprise, energized, admiration, respect, desire, inspiration, anticipation, acceptance, enchantment, hope, calm, love, amusement, relief, euphoria
Low frequency (7) (sometimes to rarely)	Dreaminess, courage, kindness, sympathy, worship, lust, alarm
Least frequency (14) (rarely to never)	Jealousy, isolation, anxiety, shyness, anger, fear, contempt, irritation, sadness, boredom, dissatisfaction, disappointment, shame, disgust

other emotions, $p < 0.05$). The emotions least elicited by the designers are irritation, sadness, boredom, dissatisfaction, disappointment, shame, and disgust (disgust least elicited as compared to 29 other emotions, $p < 0.005$; disappointment least elicited than 28 other emotions, $p < 0.005$; and each of the emotions—irritation, sadness, boredom, dissatisfaction, and shame—least elicited than 27 other emotions, $p < 0.005$).

4 Summary of Findings and Discussion

The reported elicitation frequency of all the general intentions (e.g. comprehension, attraction, etc.) is high, with minimum average frequency score of 3.5, suggesting that the lowest elicitation frequency ranges from 'sometimes' to 'often'. Our findings indicate that while some general intentions (e.g. comprehension, attraction) are elicited more frequently, some are elicited less frequently (e.g. recognition), as compared to other intentions. The reasons behind these differences might be explained by different aspects. Elicitation frequency of a specific intention, as reported by the professional designers, indicates the proportion of design projects in which they may have elicited the intention. Some intentions can be broadly applicable, whereas some can be narrowly applicable. In other words, some intentions can be important in the design of products from a broad range of categories (e.g. cars, electronic gadgets, kitchen utensils, etc.), whereas some can be important only in a small range of product categories. It is likely that professional designers will consider and elicit broadly applicable intentions in most of the design projects. For example, the intention 'comprehension', which is about supporting users in understanding how a product works, is important in a broad range of product categories. 'Comprehension' is applicable in the design of cars, mobile phones, watches and even a toilet brush, because consumer or users will look for messages about how to use a product from all these product categories. On the other hand, the intention 'recognition', which is about designing a product as coming from a particular country, brand, tradition, etc., can be applicable to some particular product categories, e.g., recognition can be more important in the design of cars than in the design of combs, because consumers or users may assign more value to a brand when purchasing a car than a comb.

Some attributes, e.g. high-quality, modern, innovative, reliable, etc., are frequently elicited. This finding suggests that these attributes are elicited in most of the design projects that designers had worked on, resulting into their high frequency score. Professional designers are likely to know which attributes are critical for product success, since they have better access to information on target markets, preferences of consumers, clients, and trends in product styling, through a range of information sources such as clients, market researchers, consumers, the Internet, magazines, etc. Because product failures could have serious financial and legal consequences for companies or consultancies designing products, professional designers will consider and implement those attributes which are critical for product success. This suggests that the frequently elicited attributes are broadly applicable and important in market success of a variety of products. Similarly, some emotions (e.g. joy, satisfaction, pride) appear to be applicable to products from a broad range of categories, and are therefore likely to be implemented in many design projects, resulting into their high frequency score.

Rarely elicited attributes (e.g. dishonest, ugly) may be narrowly applicable or least important for product success, resulting into their low frequency score. For example, the attributes ugly and dishonest tend to communicate negative messages and maybe applicable in the design of products from a narrow range of categories, and therefore designers will rarely or never elicit such attributes. Likewise, some emotions (e.g. shame, disgust) are least elicited.

While there are 11 attributes in the high frequency set, i.e. in the 'always to often' frequency range, there is not a single emotion in this frequency range (see Figs. 2 and 3). A possible explanation for this finding is that emotions can be more abstract than attributes; for example, as compared to attributes, people may find it difficult to sense and perceive emotions in the visual appearance of products. In addition, designers may find it difficult to embody abstract emotions in the design of products; whereas, it can be relatively easy to embody attributes.

This research has implications for design research and education. The findings reveal that some attributes and emotions are frequently elicited, as reported by the professional designers. It is important to understand the strategies that professional designers use in eliciting these high-frequency attributes and emotions. While there are a few studies on understanding the strategies used by the professional designers in eliciting the emotion 'surprise' (e.g. [25]), there is absence of such studies on other high-frequency attributes or emotions. Knowledge about strategies of professional designers in eliciting such attributes and emotions can form a sound foundation upon which methods or pedagogical interventions can be developed to assist design students or novice designers in learning the strategies to elicit attributes and emotions, which are critical in market success of products from a broad range of categories.

The findings of our research reveal which attributes and emotions are frequently or rarely elicited by the professional designers. It is important to note that these findings are revealed through a survey. It is therefore crucial to note that the research has limitations associated with the survey methodology; for example, the results are self-reported by the professional designers and their answers could be biased. While our findings can be applicable to other professional designers with similar background, we need to be careful in such generalization. The elicitation frequency of emotions and attributes as reported by the participating designers can vary depending on the designers' professional settings and cultures.

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Inspiration in Product Form Design: A Survey of Professional Industrial Designers

Santosh Jagtap

Abstract Inspiration has long been considered important in many creative professions including industrial design, which plays an important role in shaping visual appearance of products. A product's visual appearance has a significant effect on consumer response and product success. In the form design process, industrial designers play an important role in formulating intended consumer response (i.e. intentions), and in generating and evaluating concepts to effectively communicate the intentions. They may seek inspiration from a variety of sources not only to generate ideas to realise intentions, but also to analyse and communicate intentions. However, there is little or no knowledge about which inspiration sources (e.g. similar products, dissimilar products, etc.) and inspiration media (e.g. images, text, etc.) they use in their activities associated with intentions. We carried out a survey with 55 professional industrial designers to address this knowledge gap.

Keywords Inspiration · Product aesthetics · Product form design · Idea generation · Consumer response · Industrial designers · Product styling

1 Introduction

Inspiration has long been associated with creative professions such as music, art, science, engineering, architecture, and industrial design, just to name a few (e.g. [7, 8, 11]). The field of industrial design is closely associated with a variety of tasks, including the process of shaping visual appearance of products. The visual

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appearance of products plays a key role in the consumer perception and evaluation of product properties, and has an effect on how products are interpreted, approached and used [5, 19]. Consumer or user response to a designed product is often stimulated by visual information as the vision system provides data at higher speed and rates [18]. Based on the visual appearance of a product, consumers or users make judgements about its (un)attractiveness, interpret its function and mode of use, and make association between its characteristics and their own identity [4, 6, 10, 15]. A product's visual appearance is thus a key determinant of consumer response and product success [1, 2].

The design of products is crucial in determining consumer response and product success [1]. In the design process, designers play an important role in formulating intended consumer response (i.e. intentions), and in generating and evaluating concepts to effectively communicate the intentions [12]. In the design process, designers may attempt to elicit specific intentions through the visual appearance products. For example, a designer may have an intention to elicit specific attributes, e.g. 'innovative', 'reliable' or 'mature', through the visual appearance of products. Activities associated with intentions, e.g. *analysing intentions* (e.g. defining intentions, understanding the context of intentions, framing intentions, etc.), *communicating intentions* to stakeholders such as clients, marketers, retailers, etc., and *generating ideas* to realise intentions, are important in shaping visual appearance of products [5]. In these activities, designers may seek inspiration from a range of sources (e.g. similar products, non-products, etc.) using media such as images, objects and text [5, 7, 9].

Several research studies, from fields such as aesthetics, product design, psychology, and marketing, have been devoted to studying how consumers respond to products [3, 16]. While design research is important in understanding and improving design practice and education [13, 14], design researchers have given little attention to the process of shaping visual appearance of products [5, 12], excepting some research studies (e.g. [17], see Fig. 1). This limits our ability to develop tools and methods for improving current practice and education of the form design process.

While the form design process is important in shaping visual appearance products, there is little or no knowledge about which inspiration-sources and media designers use in: (1) analysing intentions, (2) communicating intentions; and (3) generating ideas to realise intentions. This research aims to fill this gap in the

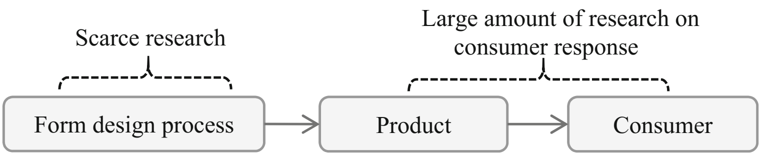

Fig. 1 Scarce research on aesthetic design process (adapted from Jagtap et al. [12])

knowledge about the form design process. To address this research aim, we conducted a questionnaire study with 55 professional industrial designers.

2 Research Methodology

We developed an online questionnaire using 'Google Forms' to identify inspiration sources and their media that designers may use in shaping products' visual appearance, specifically in their three activities—analysing intentions, communicating intentions, and generating ideas to realise intentions. The questions were iteratively formulated and refined, based on an extensive literature review, discussions with researchers and practicing designers, and a pilot study. The requirements about minimising the effort required by respondents and increasing the likelihood that they would complete the questionnaire were also taken into account. The pilot study, in which professional industrial designers participated, indicated that the designers spent less than 12 min to answers the questions.

In developing the questionnaire, we selected studies from the literature that investigated aspects of the form design process and perspectives of designers, because this study focuses on the practice of industrial designers about their use of inspiration in the form design process. For example, in the case of questions regarding inspiration sources, we used findings of [5, 7], because based they have mentioned some inspiration sources that designers may use in the design process. In the questionnaire, we included five sources of inspiration: (1) similar products (e.g. products within the category of the product that is being designed), (2) dissimilar products (e.g. products from other categories), (3) non-products (e.g. plants, animals, etc.), (4) historic products (e.g. cultural artifacts), and (5) works of art. We used three media of inspiration sources—images, objects and text—as used in the study of Gonçalves et al. [9]. Gonçalves et al's study focused on professional designers' general activity of idea generation. Their study has not investigated designers' use of media in the activities of analysing and communicating intentions and generating ideas to realise intentions, specifically in shaping visual appearance of products. Thus, our study is different, as compared with their study.

A pilot study was carried out to ensure that the respondents were interpreting the questions as intended. Replies to the questions took the form of 5-point Likert scales, see Table 1. In the case of questions related to inspiration sources, the scale assessed the frequency of using those sources (always, often, sometimes, rarely and never), and about the questions related to the inspiration media, it assessed the importance given to the media (very important, moderately important, neutral, slightly important, not at all important) (see Table 1a, b). In total, 55 professional designers from India participated in the survey. The survey was distributed through emails to existing contacts as well as contacts identified through Internet searches of industrial design consultancies and companies.

Table 1 Example of the questionnaire

(a) An example-question about inspiration sources					
In understanding intentions during the process of shaping visual appearance of products, which sources of inspiration do you use?					
	Always	Often	Sometimes	Rarely	Never
Similar products	○	○	○	○	○
…	○	○	○	○	○

(b) An example-question about mediums of inspiration sources					
In understanding intentions, how important are the following mediums of inspiration sources?					
	Very important	Moderately important	Neutral	Slightly important	Not at all important
Images	○	○	○	○	○
…	○	○	○	○	○

3 Findings

In total, 55 designers—44 males and 11 females—participated in the survey (see Table 2). They answered all the questions about inspiration sources and inspiration media.

3.1 *Sources of Inspiration*

Designers reported they use the inspiration source ‘similar products’ most frequently in the analysing intentions (M = 4.22, SD = 0.71), with usage frequency between always to often on a scale from 1—never to 5—always. In analysing intentions, the usage frequency of the remaining inspiration sources is between often to sometimes. A repeated-measures ANOVA was computed to assess the usage frequency of the inspiration sources in analysing intentions. Mauchly’s test showed that the assumption of sphericity was violated [$\chi^2(9) = 17.076$, $p < 0.05$]. A Greenhouse–Geisser correction indicated that the frequency of using inspiration sources differed significantly for the designers [$F(3.417, 184.494) = 13.116$, $p < 0.01$, $\eta_p^2 = 0.195$]. Post hoc tests with Bonferroni correction revealed that the source ‘similar products’ is used most frequently in analysing intentions ($p < 0.05$, in relation to all other inspiration sources) (see Fig. 2a).

Table 2 Overview of the professional designers’ experience

Years of experience	Number of designers
Less than 5	13
Between 5 and 10	23
Between 11 and 15	15
Between 16 and 20	2
21 and above	2

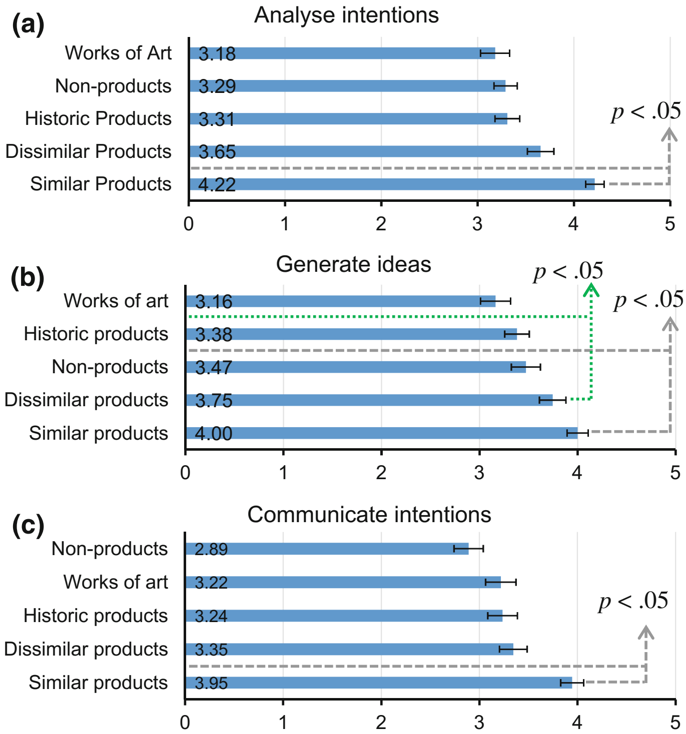

Fig. 2 The sources of inspiration used by the industrial designers in understanding and communicating intentions, and in generating ideas to realise intentions, with standard error of means indicated (Scale: 1—never, 2—rarely, 3—sometimes, 4—often, 5—always)

The designers reported that in generating ideas they ‘often’ use the inspiration source ‘similar products’ (M = 4, SD = 0.79), followed by the remaining sources (see Fig. 2b). There was a statistically significant effect on how frequently the designers reported using five inspiration sources in generating ideas [$F(4, 216) = 6.512$, $p < 0.01$, $\eta_p^2 = 0.108$. The assumption of sphericity was not violated: $\chi^2(9) = 14.742$, $p > 0.05$]. Post hoc tests with the Bonferroni correction indicated that information on similar products was reported to be used significantly more than two other sources—works of art and historic products ($p < 0.05$, Fig. 2b). Information on dissimilar products is used more frequently than on works of art ($p < 0.05$, Fig. 2b).

The most frequently used inspiration source in communicating intentions is ‘similar products’, with usage frequency close to ‘often’ (M = 3.95, SD = 0.87). The least used inspiration source in communicating intentions is non-products (M = 2.89, SD = 1.10). In communicating intentions, the reported frequency of using the five inspiration sources differed significantly [$F(2.988, 161.342) = 9.975$,

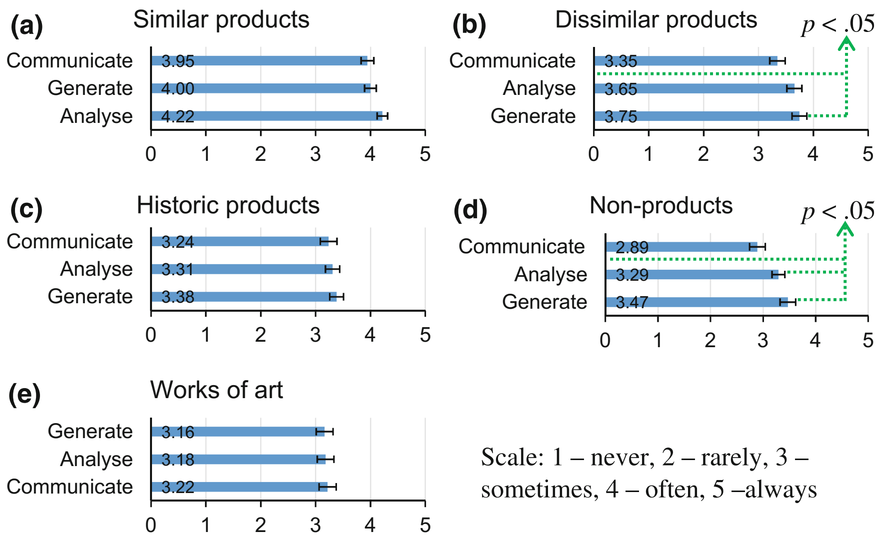

Fig. 3 The sources of inspiration across three design activities—understanding intentions, communicating intentions and generating ideas, with standard error of means indicated

$p < 0.01$, $\eta_p^2 = 0.156$, with Greenhouse–Geisser correction, as assumption of sphericity was violated: $\chi^2(9) = 29.883$, $p < 0.05$]. Post hoc tests with the Bonferroni correction indicated that the inspiration source 'similar products' is used most frequently (used more often than 4 other inspiration sources, $p < 0.05$, see Fig. 2c).

When comparing differences in usage frequency of the five sources (similar products, non-products, etc.) across three activities (analysing intentions, communicating intentions, etc.) (see Fig. 3), we found significant differences only in the case of dissimilar products [$F(1.620, 87.466) = 4.975$, $p < 0.05$, $\eta_p^2 = 0.084$. The assumption of sphericity was violated: $\chi^2(2) = 14.182$, $p < 0.05$] and non-products [$F(1.706, 92.141) = 14.001$, $p < 0.01$, $\eta_p^2 = 0.206$. The assumption of sphericity was violated: $\chi^2(2) = 10.011$, $p < 0.05$]. Post hoc tests with the Bonferroni correction indicated that the source 'dissimilar products' is used more frequently in generating ideas than in communicating intentions ($p < 0.05$, see Fig. 3b), and that the source 'non-product' is used more frequently both in generating ideas and analysing intentions than in communicating intentions ($p < 0.05$, see Fig. 3d).

3.2 *Inspiration Media*

The designers rated images and objects as very and moderately important in analysing intentions (images, M = 4.71, SD = 0.53 and objects, M = 4.65, SD = 0.55), in communicating intentions (images, M = 4.82, SD = 0.43 and objects, M = 4.71, SD = 0.53), and in generating ideas to release intentions (images, M = 4.76, SD = 0.43 and objects, M = 4.64, SD = 0.62). The reported importance given to the inspiration media differed significantly in: (1) analysing intentions [$F(1.762, 95.167) = 54.255$, $p = 0.001$, $\eta_p^2 = 0.501$. The assumption of sphericity was violated: $\chi^2(2) = 7.677$, $p < 0.05$]; (2) generating ideas to realise intentions [$F(1.715, 92.621) = 52.553$, $p < 0.001$, $\eta_p^2 = 0.493$. The assumption of sphericity was violated: $\chi^2(2) = 9.623$, $p < 0.05$]; and (3) communicating intentions [$F(1.309, 70.665) = 35.416$, $p < 0.001$, $\eta_p^2 = 0.396$. The assumption of sphericity was violated: $\chi^2(2) = 39.829$, $p < 0.05$]. Bonferroni post hoc tests indicated that both images and objects were significantly more important for the designers than text in analysing intentions ($p < 0.05$), in generating ideas to realise intentions ($p < 0.05$), and in communicating intentions ($p < 0.05$) (see Fig. 4).

When comparing the importance given to the information media (images, objects and text) across three activities (e.g. analysing intentions, communicating intentions, etc.), we found significant difference only in the case of text [$F(2, 108) = 3.326$, $p < 0.05$, $\eta_p^2 = 0.058$. The assumption of sphericity was not violated: $\chi^2(2) = 3.054$, $p > 0.05$]. Post hoc tests with the Bonferroni correction indicated that the designers gave more importance to text in communicating intentions than in generating ideas to realise intentions ($p < 0.05$, see Fig. 5a).

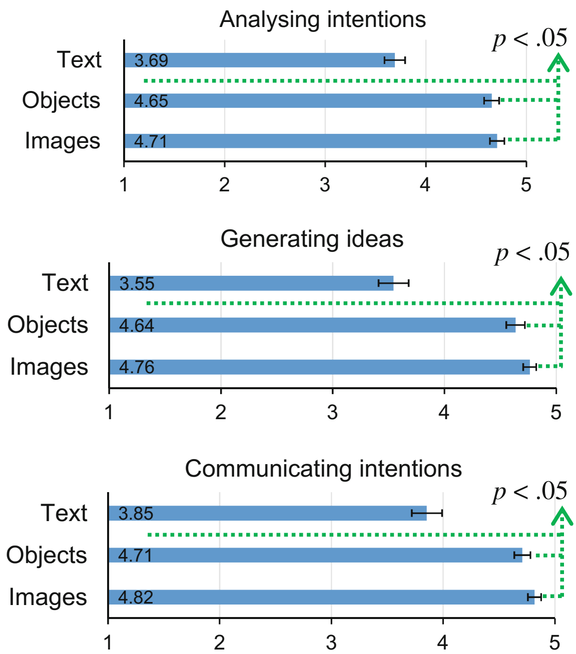

Fig. 4 Importance given to the inspiration media by the designers, with standard error of means indicated (Scale: 1—not at all important, 2—slightly important, 3—neutral, 4—moderately important, 5—very important)

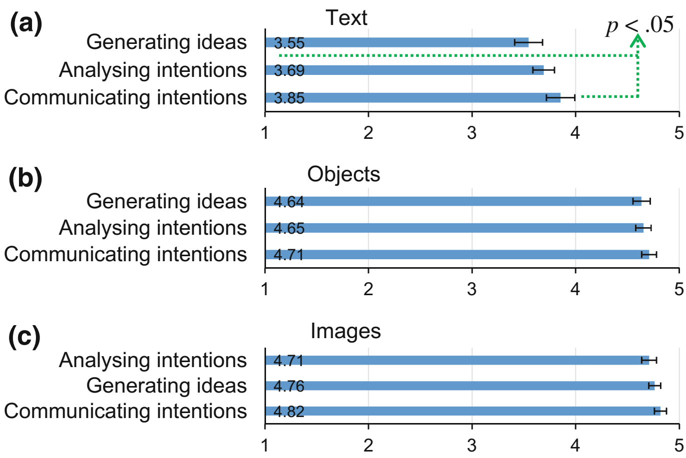

Fig. 5 The inspiration media across three design activities—understanding intentions, communicating intentions and generating ideas, with standard error of means indicated (Scale: 1—not at all important, 2—slightly important, 3—neutral, 4—moderately important, 5—very important)

4 Summary of Findings and Discussion

4.1 Sources of Inspiration

This research, through a survey of 55 professional industrial designers, examined their use of inspiration in analysing and communicating intentions as well as in generating ideas to realise intentions. One of the findings is that the designers frequently use the inspiration source ‘similar products’ in analysing intentions. We propose the following two reasons to explain this finding. First, in competitive markets, product success depends on how well it competes with similar products, because customers explicitly or implicitly compare similar products when they make a purchase decision. Serious financial consequences of product failure in such competitive markets mean that the professional designers will attempt to design a product so that it can successfully compete with similar products, requiring them to seek inspiration from similar products in analysing intentions. Second, the finding that the designers frequently use inspiration from similar products in analysing intentions suggests that in most of the design projects that they work on can be about designing products, which have similar products to compete with. In other words, it is rare that professional designers will design a product, which will satisfy an entirely new function or will not have any similar products to compete with.

As with analysing intentions, designers frequently use the inspiration source ‘similar products’ in communicating intentions, indicating its importance and effectiveness in communicating intentions. Because a designed product needs to compete with similar products in competitive markets, designers will use references to products similar to the one being designed when they communicate intentions with stakeholders such as clients, manufacturers, marketers and retailers.

While the designers frequently use the inspirational source ‘similar products’ in analysing and communicating intentions, they frequently use more information sources in idea generation, including similar products, dissimilar products and non-products. This suggests that by seeking inspiration from a range of sources, designers may encourage a flow of ideas, indicating an exploratory nature of their idea generation activity.

4.2 Inspiration Media

The findings about the importance given to the media of inspiration-sources indicate that both images and objects are considered highly important in analysing and communicating intentions as well as in generating ideas to realise intentions. This suggests the importance of not only images but also of objects in the process of shaping visual appearance of products. Images are easily accessible, e.g. through magazines or search engines on the Internet. Furthermore, industrial designers, in general, keep collections of images, either in digital or non-digital formats, which they can use in the current or future design projects.

As compared to images, it may take more time and effort to access objects. Despite this, the designers consider objects to be highly important, indicating important role of objects in the design process. Professional designers’ access to financial and material resources can enable them to access and use objects in the design process. In general, they also make tangible prototypes, e.g. using 3D printing or some other process. High importance attributed to objects also suggests that they can provide more information, e.g. details about surface finish, colours, form, information about how a product is assembled or how it can be used, etc. Designers may use such additional and detailed information provided by objects in analysing and communicating intentions, and in generating ideas.

Comparison of the medium ‘text’ across three activities (e.g. understanding intentions, communication intentions, and generating ideas) shows that it is reported to be significantly more important in communicating intentions (see Fig. 5a). Designers may use annotated sketches, images or some specific words in communicating intentions to different stakeholders, resulting into its higher importance in communicating intentions, as compared to analysing intentions and generating ideas.

The findings reported in this paper suggests areas for further design research. It would be interesting and important to understand how designers use the inspiration source ‘similar products’ in understanding and communicating intentions, and how they seek inspiration from similar, dissimilar and non-products in generating ideas. It would also be useful to understand how they use images and objects to seek inspiration in their activities of understanding and communicating intentions, and in generating ideas.

4.3 Limitations

The findings of our research reveal which inspiration sources are frequently used and which media of these sources are considered more or less important in shaping visual appearance of products. It is important to note that this research has limitations associated with the survey methodology; for example, the results are self-reported by the professional designers and their answers could be biased. While our findings can be applicable to other professional designers with similar background, we need to be careful in such generalization. The frequency of using inspiration sources and importance given to their media can vary depending on the designers' professional settings and cultures. Understanding aspects of the form design process in a variety of cultural and professional setting, using a variety of data collection methods, can usefully assist in gaining rich comparative accounts of those aspects.

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Modeling Design Strategies for Package Graphics: A Study of Hair Care Products Among Young Indian Users

Toney Sebastian, Pradeep Yammiyavar and Stevan Jones

Abstract A study of hair care package graphics was conducted among young Indian users to examine the effect of design elements on successful user acceptance. The study revealed that typography of the brand name should be given the highest weightage among all texts, and information of higher importance should be placed towards top one third of the graphics to capture user's primary attention. The study was performed using package graphics of eight hair care products including domestic and global brands, selected using a purposive sampling technique. A descriptive qualitative content analysis using a code sheet incorporating designer's perspective was performed to identify the ranking of importance of design elements in package graphics. Further, a small scale quantitative and qualitative user study was conducted to assess if the qualitative content analysis based assessment is matching user preferences. Validation of the findings was done using an Eye Movement Recorder based study.

Keyword Package graphics · Indian users · Design strategy · User acceptance · Eye movement recorder

1 Introduction

Package design, particularly graphic design has a great role in influencing purchasing decisions. According to a research done by Henley Centre, about 73 percent of the purchase decisions are made at point of sale [1], which shows the

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importance of package graphics in purchase decisions. In this competitive world, companies are looking for ways to stand out, and reach target users more effectively over competition [2]. Companies often have a visual strategy in place to secure a competitive advantage in the user's mind [3]. Marketers realize that the reactions of the target user are highest at the visual level, especially in the tangible consumer goods market [4]. Design should ensure that the brand stands out at shelf, recognized, and included in the products under consideration [5]. Many researchers advocated usage of packaging as the biggest medium of communication because of its wide reach to purchasers of the category and its presence at the moment when the purchase decision is made [6–8]. Package graphics also drives high level of involvement for users who actively scan packages for information, which makes it an essential element in branding [5]. Good package graphic designs would reward the marketer with strong stopping and closing power at the point of sale, help drive brand awareness, establish brand identity and ultimately helping the companies to grow their bottom line.

Over the past several years, design elements in advertisements and packaging have attracted considerable amount of academic research [9–17]. Kim [9, 10] did a generic investigation on role of design elements in the design of advertisements and branding. Kim [9] showed how individual design elements such as shape, layout, and logos operate in advertising. Kim's [10] study of the role of color in branding proposed the use specific color for targeting specific brand personality. Vyas [11] suggested that the packaging design elements have an influence on choosing, getting attracted, liking and purchasing the product. Silayoi and Speece [12] found that visual elements of the package, particularly graphics and color have great influence on user's choice of the product, by breaking through the competitive clutter. Mutsikiwa and Marumbwa [13] investigated impact of package design elements such as color, material, package instructions and typography on purchase decisions for dairy products in Zimbabwe, and observed that not all design elements trigger purchases, instead designs in which elements that are properly blended is appealing to consumers and triggered purchase. Riaz et al. [14] showed that attractive packaging designs have strong influence on the buying behavior of female consumers in cosmetic category.

Indian users were also subjected to researches in package design [15–17]. Khan and Khan [15] investigated influence of packaging on female skincare users in Indore, and observed that products with attractive packages have a perception of higher quality. Shekhar and Raveendran [16], assessed effect of visual and informative cues on purchase decisions in chocolates category among senior citizen in Kerala, and remarked that both visual and informative cues have positive correlation to purchasing decisions. Gopal and George [17] evaluated FMCG packages in Indian context, suggested that creative elements in packaging could actually trigger an increase in sales. Although academic research has addressed a number of different areas of package and package graphics design, category specific design especially categories like haircare is still under researched in India. Haircare is a fast growing category in India, with about 14% of growth and total market size of INR 154.7 billion in 2014 [18]. Companies often have a category and brand specific design strategy to create and maintain differentiated brand identities, and often these strategies are different for categories like hair care compared to other categories such as food or skincare. Further, the type of products in hair care is different from other categories. Therefore researches in design strategies in haircare would attract interest from both academicians as well as design managers in the category.

A study of hair care package graphics was conducted among young Indian users to investigate effect of design elements on successful user acceptance. The study incorporated both designer's and user's perspective, using qualitative and quantitative techniques. Validation of the observations was done using an Eye Movement Recorder based user evaluation. The research provided insights on important design elements required for successful acceptance of hair care package graphics by young Indian users. Findings would be relevant for design managers who are designing for young Indian users and academicians who are investigating package graphic designs.

2 Research Methodology

A descriptive qualitative content analysis by incorporating a designer's perspective was performed by the researcher, for the isolation and assessment of different design elements used in hair care package graphics. Followed by this, an image test using traditional qualitative and quantitative research was done for assessing user acceptance. Further, an Eye Movement Recorder (EMR) based study was conducted among the same user group to validate the findings. Image tests and EMR user evaluation studies were conducted among 11 users, who are students of IIT Guwahati as well as natives of different parts of India. All the studies were performed at UE lab, IIT Guwahati, from Sept 24 to 26th, 2015.

2.1 Qualitative Content Analysis

Qualitative content analysis has a long history in research for analyzing text data, starting from 18th century. Qualitative content analysis is structured, systematic and analytic. According to Maxwell [19], the main strategy behind qualitative research is coding, which is aimed to take the data and rearrange them into groups that facilitate comparison between things in the same group, which then help in the development of theoretical concepts. One of the limitations of content analysis is, the findings for a particular content are limited to the framework of the groups and the definitions employed in that analysis. In the current research, this limitation was minimized by precisely defining the groups and elements used for the study, so that other researchers can apply the same tools to the same data and achieve the same results. Details of the code sheet used are captured in Sect. 2.4

2.2 Image Test

Image tests using traditional qualitative and quantitative techniques are widely used in package design research to get insights on consumer attitude and preferences [8].

2.3 Eye Movement Recorder

Eye tracking studies are used to track the movement of the pupil as it moves across an image [20]. This technique has a history of over 30 years, and is now the leading technology to measure how humans 'see' products. Eye tracking is highly effective at measuring the way users navigate a design, i.e., what they look at first, what pause longer, and what they go back to and study again. As long as designs are being tested under exactly same circumstances and with significant number of users, EMR can be considered accurate. One drawback of EMR based study is, it evaluates the design isolation and the total context final execution is not considered. For example, elements such as promotions, advertising, etc.… are not considered when evaluating design using eye tracking. This limitation is not relevant for current study as scope of current study is limited to design elements of package graphics, and not to purchase decisions.

2.4 Sampling

A purposive sampling technique was used for this study. A purposive sample is one in which the researcher uses personal judgment to determine if certain items of a population best serve the purpose of the study [21]. Purposive sampling is relevant for this study as no prior research is available to the best of knowledge, in the area of hair package graphics among Indian consumers.

2.5 Materials

Package graphics used for the study were collected from Amazon website [22] using an internet enabled computer. A total of eight package graphics were collected, with a good mix of global (Pantene, Dove and Herbal Essence brands) and domestic brands (Ayush, Patanjali and Indulekha brands). For global brands, package graphics of products marketed in both USA and India were collected (for Pantene and Dove brands), while for Herbal Essence brand, only one version was available. To avoid variability due to product type and color of the bottle, shampoo products were chosen for the evaluation, with 'white' as the primary package color.

For Qualitative content analysis, a code sheet was developed with inspiration form code sheet used in Rhoads [23]. Rhoads's code sheet focused on design principles to assess print and website advertisements of beauty care products. In the current study, the code sheet was used for package graphics, which was developed focusing on typography, color, presence of logo, and layout and illustration style. This coding sheet enabled the researcher to compare and analyze design strategies of the graphics studied. Following are the code sheet elements and definitions used for the study.

- Brand: Write the brand name of the product
- Packaging: Describe what type of package is used. Can the product form be identifiable with the package?
- Typography: Is there a specific/unique typestyle used in the package graphics? This code does not refer to typography used in the logo
- Color: Is there a color scheme present in the package graphics? Does the graphics feature color in the text?
- Does color used in the package appear to be a main focus? Does the package use one color, spot color, or full color? Please describe and explain. Also record the colors emphasized, if any.
- Logo: Record whether a logo is used within the package graphics. Is the logo an image only, or does it include text?
- Overall Design principles: Brief discussion of what the designer wanted the consumer to look at.

For qualitative and qualitative user evaluations, a questionnaire was developed uniquely for this study, due to the absence of published questioners. Qualitative evaluations were done by showing images in groups (one group of all eight images (Fig. 1), one group of domestic packages, one group of USA packages, and two groups of two packages (Indian and USA Pantene and Indian and USA Dove).

Fig. 1 Images used for the research. From *left*, Dove USA, Pantene USA, Herbal Essence, Ayush, Indulekha, Patanjali, Dove India, and Pantene India (*Source* www.amazon.com [22])

Fig. 2 Eye movement recorder based study conducted at UE Lab, Dept. of Design, IIT Guwahati

A few questions were asked to understand user preferences of the package graphics, which included, which graphics is attractive, why do you think it is attractive, which is not attractive, why it is not attractive, which one looks most ‘premium’ etc. For quantitative evaluations, individual package graphics were shown one after another, and users were asked to rate each image against 18 keywords on a scale of one to five. Users were asked to rate the keyword five if they strongly agrees to the keyword and 1 if strongly disagree. The scale was balanced at three, for neither agree nor disagree. Key words tested included beautiful, premium, bad, boring, ordinary etc.

For Eye Movement Recording (EMR), Tobii eye movement recorder at UE Lab, IIT Guwahati was used. Package graphics were shown the same as it was shown for qualitative and quantitative studies (one after another as well as in groups) (Fig. 2).

3 Results and Analysis

Results and observations are grouped into qualitative content analysis, qualitative and quantitative user evaluation and Eye Movement Recorder based observations.

3.1 Qualitative Content Analysis

Observations on typography, logo and color are done based on qualitative content analysis.

Typography

1. All designs given highest importance for brand name among texts used. All designs used largest font size to write brand name.
2. Most of the graphics (7 out of 9) used brand name as the top most text to drive primary user attention. Pantene India and Herbal Essence were the exceptions, as they used the topmost text to represent a pricing promotion and newness respectively.
3. It is observed that, too much text information on graphics as in Ayush and Herbal Essence is creating clutter, which may make the designs aesthetically less attractive.

Logo

1. Among package graphics assessed, only brands with well-known international presence had logo (Pantene India, Pantene USA, Dove India, Dove USA, and Herbal Essence). None of the domestic brands had logo.
2. Most of the graphics (four out of five) positioned logo at the middle, right below the brand name with the exception of Herbal Essence. Herbal Essence positioned Logo above the brand name.
3. Most of the domestic brands used the area below brand name to visualize ingredients in the product, with the exception of 'Ayush'. Ayush neither had logo nor ingredient visualization.
4. Herbal Essence had both logo and ingredient visualization on pack, which make the design very busy.
5. Visuals and Logo on global brands like Pantene and Dove have higher level of clarity compared to visuals on domestic brands like Patanjali and Indulekha, which would impact the overall acceptance of design

Color

1. All designs used number of colors conservatively, which is consistent with guidelines established by Lidwell et al. 2010 [24].
2. Designs of Pantene and Ayush used gold to drive premium-ness while Dove used glossy blue and gold for premium-ness. Herbal Essence used green to communicate 'Herbal', while domestic brands like Indulekha used colors in nature to communicate natural (natural ingredients are used).
3. Pantene India used gold color to highlight the entire cap area, while Ayush and Pantene USA used a thin gold band. Both are elevating the premium-ness of the bottle. Herbal Essence used green color (consistent with color of logo), to highlight cap opening area. All these are expected capture user attention on closer look.

3.2 Qualitative and Quantitative User Evaluations

Observations based on qualitative and quantitative consumer evaluations were consistent with the observations from qualitative content analysis. Consumers identified package graphics of Pantene India, Pantene USA, Dove India and Dove USA as noticeably better and attractive compared others, primarily because of overall simplicity (not too many contents), use of logo, and use of gold and/or glossy blue colors.

Users also appreciated logo of Herbal Essence, gold bands in Pantene USA and Ayush, golden cap color of Pantene India, and green cap opening of Herbal Essene. Among domestic brands, graphic design of Ayush had higher acceptance because of use of gold band. Package graphics of Indulekha and Patanjali were identified as least attractive designs. Results from quantitative user evaluation are presented in Figs. 3 and 4.

3.3 Eye Movement Recorder

Eye movement recorder data analysis gave insights on user's viewing pattern. When all the eight graphics shown together, most of the attention were focused on the upper half of the bottle, which gives indication that Information with higher importance should be placed towards the top of the bottle (upper half), while lesser important information may be placed towards the bottom. Consumers may not pay attention to the bottom half on the first look. Further EMR also helped in validating the findings from other studies. When individual package graphics, groups of two

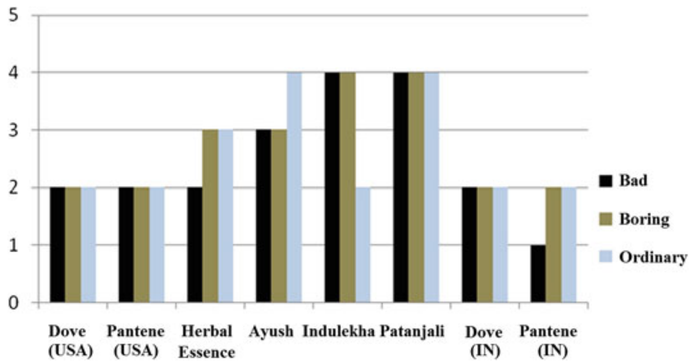

Fig. 3 Chart representing median score of user rating for keywords bad, boring and ordinary. Scale 5 represents Strongly Agree, 4 for Agree, 3 for Neutral, 2 for Disagree and 1 for Strongly Disagree

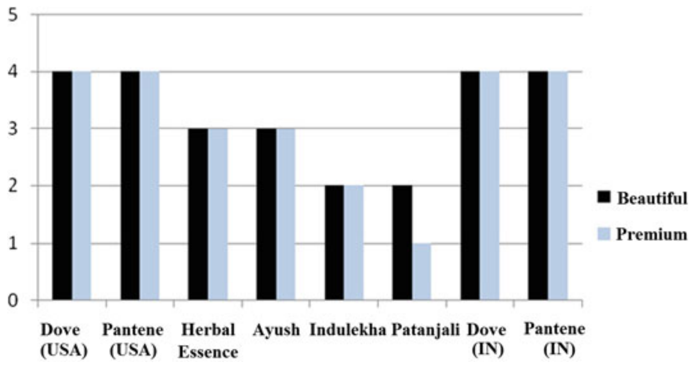

Fig. 4 Chart representing median score of user rating on a scale of one to five for keywords beautiful and premium (N = 11). Scale 5 represents Strongly Agree, 4 for Agree, 3 for Neutral, 2 for Disagree and 1 for Strongly Disagree

Fig. 5 An example of viewing pattern from EMR study, showing user did not look at towards bottom of the design

and groups of three graphics were shown, brand names, logos, gold bands, ingredient visualizations, and cap color highlighting's were the elements that captured most of the attention (Fig. 5).

4 Discussion

The current study gives a clear indication of the ranking of importance of design elements and key elements needed for developing a successful package graphics for young Indian users. While prior researchers like Kim [10], investigated effect of color as a specific design element, current research gives further insights on all design elements in a package graphics. Although Vyas [11, 14, 15] suggested that the packaging design elements have an influence product selection, it did not provide insights on specific ways to improve the design. Current research helps to close the gaps by providing specific insight on ranking of importance of design elements. Based on the study, we propose that package graphic designs should give highest weightage for typography of the brand name, with largest font size among all texts, and by positioning it towards the top of the package. The study also suggests that designs with presence of a logo or an ingredient visual of higher level of clarity will have better aesthetic acceptance. Designs may give second highest weightage for this, after typography of brand name. Further, the study advocates coloring the cap or cap opening area with colors of the logo to capture additional user attention. The findings also support use a gold band on the cap, or highlighting the cap or cap opening are with gold color to drive user's premium perception. For products that use nature or natural ingredient communication, colors similar to the ingredient visualization may be used instead of gold. The research also suggests that designs should avoid cluttering of too much text and visuals information, as it will make the design aesthetically less attractive. Further, information with higher importance should be placed towards the top of the bottle (upper half) to capture primary user attention. Information with relatively lesser importance may be placed towards the bottom; however designs should avoid too much texts and visual information here to avoid the risk of resulting in aesthetically less attractiveness.

Findings from the current study give important guidance to design managers who are designing for successful acceptance of young Indian users. Applying the findings from current study in developing package graphic designs would result in relatively higher user acceptance of the designs. Current research may also have direct application to e-commerce business, as all the evaluations were done on computers. The findings need to be further evaluated with graphic designs of different colored packages, with a larger number of product sample size and higher number of user base size, including both urban and rural users and using more comprehensive statistical analysis. Evaluation with physical samples should also be conducted as most of the category business is still direct purchase from shops. Further studies involving evaluations using a more developed methodology, a method which will engage broader insights from the critical approach to advertising and branding might be interesting to better understand the users overall decision making process, beyond the package graphics.

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Syncretism 5.0: Could Design Become a Meta-religion for Global Communion?

Chitra Chandrashekhar

Abstract Happiness, is every human's ultimate desire. Good, Bad, Right, Wrong, Morals, Ethics, Justice, Harmony, Unity and Peace, Do they matter? Unity and Harmony are virtues, every Designer, strives for in finding 'humane' solutions to 'wicked' problems. These virtues appear to be rather elusive to sustain throughout human history. Yet, through the crests and valleys of civilizations, people have managed to co-exist and behave somewhat synchronously across generations. How? This paper is a Designer's attempt to understand 'Design' through the analogy of 'Religion' both in the traditional and modern sense. It studies the 'syncretic' ability of 'religion' to build and maintain cohesive communities over long spans of time and suggests how Design can emulate that prowess in addressing world's urgent problems. By examining trends and developments in design practice, the paper suggests a vision for 'Design' as a '*Dharma*' that fosters 'Syncretism' for a harmonious, plural, just and happy global communion.

Keywords Syncretism · Design · World · Global communion · Sustainability · Socio-cultural · Religion · Dharma · Practice · Education · Ubiquitous · Justice · Harmony · Unity · Peace · Happiness · Problem solving · Co-creation · Tools

1 Introduction

> He who has an aim in life, an aim which is in itself true and essential, has eo ipso a religion[1]
>
> —Ludwig Feuerbach

What is (your) religion? Once 'Design' was only a profession but it has gradually altered my world view and life's philosophy, that I believe, it has made me an

[1]Chopra, R.M.:A Study of Religions, pp. 263. Anuradha Prakashan, New Delhi (2015).

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eager and devout practitioner of 'Design *Dharma*'. My ethical duty or *Dharma* is to offer humane, sustainable and synergistic solutions that aid communities to thrive symbiotically. It is both interesting and important for me to understand what makes a community. The idea that 'unity' is an integral part of the word 'community' struck me as a bolt of lightning. What is unity? In Design, we learn perception through the Gestalt theory, '*Whole is greater than the sum of its parts*'. But growing up, I have also learnt about human instincts and our eternal vices of power, control, violence, greed, prejudices, and numerous instances when they have disrupted harmony and unity. So, I was led into concluding that 'unity' was only a virtue and a construct from the world of art, design and philosophy (Fig. 1), but not true for the practical human world. How then can sustainability be achieved, unless our increasingly networked global communities learn to function, not as a homogenous, but a harmonious whole?

For answers, I traced back to our nearly 5000 years of collective human history. Patterns emerged in the rise and fall of civilizations when human societies converged to thrive and prosper but have been time and again sundered apart. I discovered that throughout history, humanity has indeed attempted to unify many times, inspite of various inherent and manufactured differences. 'Syncretism', was a word that epitomised this attempt to negotiate differences for the larger good. Originated in Greece, Plutarch mentioned this word in his work *Moralia* (1st century AD), in an essay on 'Fraternal Love'. In the Greek history of nations,

Fig. 1 Vision for unity, harmony and peace among religions and nations (*Source* Photographs by Author, India Habitat Centre and Gandhi Smriti Bhavan, New Delhi)

Syncretism referred to the confederation of Cretans, who had to reconcile their differences to form alliances and combat common external dangers. Extending this idea further, in the history of human evolution many revolutions (Fig. 2. Syncretism 1.0–4.0) have impacted the way we functioned as collective cultures and societies. All along 'Religion' surfaced as the most resilient and sustainable aspect of unified cultures. It is religion that has held people together in congregations and clusters both physically and spiritually over generations. Religions developed around the worship of the Divine or the Powerful. Over time the divine morphed from the fear or love of the forces of nature, to anthropomorphic images or symbols of formless Almighty saviour who was dreaded or loved, to a mighty King or Authority, and in our age, even Money, Science and Technology perform the same function (Fig. 2). Religions, whether traditional or modern, have sustained through a multipronged strategy guiding everyday lives and varying levels of consciousness of its peoples. Each type has its own method of organising people. Stories, mythology, philosophies, morals, ethics, values, treatises, art, architecture, festivals, rituals, habits, products etc. are generally, ways in which religions, incessantly and timelessly, manifest themselves within their respective communities. Today, many forms of old and new religions, cults or religion-like paradigms such as Science and Technology, Information Societies, Political or Financial Power etc., coexist with some irreconcilable conflicts.

When modern democracies are advocating for unity, equality and secularism, will religion get redundant? How can communities, only unified, within their own religious paradigms, unite for the larger good? As a species, we have evolved by discerning differences, then finding similarities to form collectives like tribes, races,

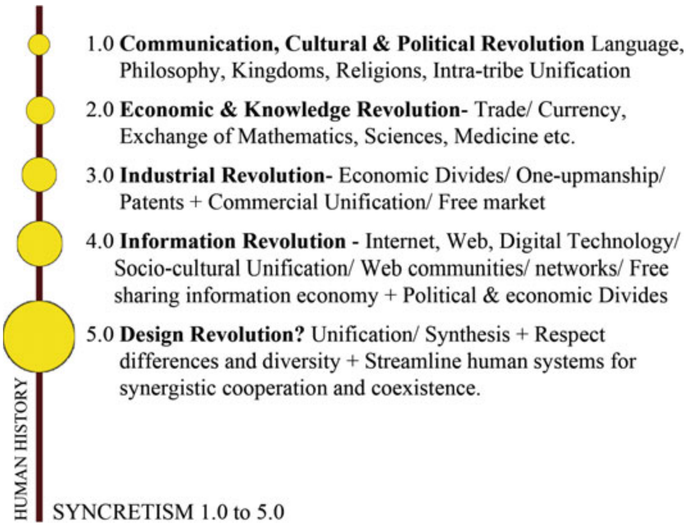

Fig. 2 Syncretism across human history (*Source* Author)

classes, occupations, religions, sects, creeds, nations, continents etc., further highlighting differences. Now is another stage to find new similarities and establish universal oneness in conscience and intentions. This is the paper's very premise, to elucidate whether and how Syncretism 5.0 is the age of ubiquitous Design, an evolved Design *Dharma* for our planet. Defining Design *Dharma* stems from understanding the meaning of Religion and its various associations that create limited but cohesive groups in the society. This paper extensively learns from trends in Design practice to postulate how Design has begun to intervene and innovate even in the most private spheres of life, much like religion. But it has the potential to supersede religion without making it redundant, thus leveraging Design's syncretism as a meta-religion.

2 Religion, Secularism and Syncretic Design Dharma

2.1 Understanding Religion

It took more than an etymological study of the various words that mean 'Religion' to understand what it truly is and does to us [1]. Derived from the Latin root word, *re* and *ligare*, Religion, roughly means 'to reconnect or bind back'. Explaining it further, would mean that the word and its function both signify binding people together and eventually to the Divine Higher Soul or Self or God or Cosmos etc. Chopra [2] carefully traces the origins of every religion to find similarities in the essence of all major world religions which he believes is the key to unity and peace in the world. He states, Christianity emerged from *Christos,* meaning bathed in Divine Wisdom. *Dharma* in Sanskrit, comes from the root *Dhr*, to hold or bind, that is to mean, living by the law of a conscious and righteous life which includes: (a) wisdom, right thoughts and knowledge or *Jnana*; (b) Devotion, Sensitivity to feelings and emotions or *Bhakti* and finally, (c) Action or *Karma*. Other words of religions, such as, the Chinese *Tao* and Islamic *Mazhab* mean 'the Way', referring to the path to righteousness, god and happiness. The Almighty figure was often designated with the role of judgement of one's earthly life, through reward or penalty. This ensured people led moral and ethical lives for the fear of the 'day of judgement'.

Since the onset of modern scientific discoveries, there has been a weakening of people's faith in ancient religions. The growing faith in Science or even Money almost makes it a new form of religion that gives hopes to its modern adherents. It offers a new path to better life in the modern material world with knowledge, status, power and wealth. Often scientists and many who are logic-centric, discard 'Religion' outright as mere tradition, blind faith, irrationality, esotericism etc. An experimental psychologist Dr. Evans, C., blatantly comments about the failure of religions to inspire people any more, in times of scientific advancements:

> For who in this day and age, now that astronauts have waddled around the moon, can really feel that the Archbishop of Canterbury has anything important to say in celestial matters?[2]

Yet, Dr. Evans, C., goes on to claim that science has limits to what it knows in the material realm and most people seek simple logical answers to deep mysteries of '*life, death, time, space, creation and destruction*' [3]. They are thus driven to choose one faith or another, or join new age (early 20th Century) cults to satiate their metaphysical and spiritual inquiries. However, at one time, Religion, Science and progress went hand in hand. Religion, whether Islam, Christianity, Jainism, Buddhism, Zoroastrianism, Judaism, Sikhism or Sufism, were all different systems to propagate wisdom from prophets, saints, mystics, sages and teachers, to maintain loving, peaceful and harmonious social communities. Their end was to serve the basic need of survival and growth both materially and spiritually. Most world religions preach values of fraternal love, compassion, mutual respect, self-less sharing and caring, honouring the environment or nature as a boundless giver or God's Nature. They almost always differed in their modes of operation such as rituals, practices, festivals, narratives etc.

2.2 Understanding Secularism

While scientists may not endorse the theological premise of religions, Einstein believed in the grandiosity of the cosmos itself instead of placing faith in a God figure. He felt it was 'religious' enough to appreciate the oneness of all matter and energy in the universe. To him, living well in peace and harmony did not require one to have religion or morals but basic humanitarian values of brotherhood and compassion. This was also the premise for all modern statesmen representing nations of the world. Secularism was their way of conducting politico-economic affairs separate from religion. In India however, secularism meant treating all religions equally, but not divorcing them from day-to-day affairs of state or nation. This must be the premise world over. Why then do we still have violence in the name of God and Religion? (Fig. 3, Gandhi) Secularism in its apathetic attitude towards religion has failed to breed tolerance. Equally so, religions that have survived millennia have failed to teach us to live in harmony and tolerance thanks to competing socio-politico-economic issues. Nations are human conglomerates and our cultures are soaked with religious values that it is impossible to estrange them from ethical conduct in modern lives. The UN Millennium Goals are a reminder of the need for us to act collectively to root out our common woes and problems necessitating blurring of superficial boundaries. Sister Nivedita rightly poeticizes about the oneness of cultures for a spiritual symphony:

[2]Dr. Evans, C.: Cults of Unreason. pp. 9. Panther Books. UK (1977).

> When need is one, and hope is one, when fear is one, and love is one, how are men to dream long that there are barriers dividing them?…and we see and we know that we are one.[3]

2.3 *Design as a Syncretic* Dharma *or Meta-religion*

To each, devotion towards his/her profession is akin to a religion/*Dharma*. Many Mathematicians and Scientists like Isaac Newton, Albert Einstein and more recently Sir Richard Dawkins and Neil De Gras Tyson have waxed praises of their discipline unraveling it in every aspect of the universe. While I may be blinded by the same devotion towards Design, I am also inspired to see how it manifests in the real world promising much the same hope as any religion would offer. To me religion or *Dharma* is a set of philosophies and world views that shape thoughts and actions such that they become a way of life. The question that baffles every contemplative human, ‘What is Life?’ is akin to the gravest be all and end all existential question for a Designer, ‘What is Design?’ While every designer creatively crafts a definition for oneself, with every generation the meaning of Design has evolved.

Since the end of the 20th Century, Design has shifted from being merely a thinking or creative tool to make pretty articles for mass production that cause inadvertent ecological imbalances (Fig. 3, Other Design Thinking). Design is now embracing new humanitarian, socio-ethical, ecological and moral standpoints. Much like Religion, binding diverse people together with an Almighty, Design urges one to appreciate our sociological relation of the ‘self’ with the ‘others’ and the larger environment. Design is imbibing secular, just, syncretic and democratic values while respecting cultural diversities through one of its virtues, Empathy. Designers are acting as bridges between both the material and spiritual facets of human experience. Designers are turning into modern day prophets and philosophers charged with the aim to illuminate the importance of both systemic and scientific thinking [4]. Designers like McDonough, W. (Fig. 3) are advocating for regenerative design philosophies such as Cradle to Cradle® and values such as ‘Design Humility’. He says Design is a ‘signal of human intentions’. His design decisions are based upon crucial questions like:

> So, what are our intentions…as a Species?…How do we love all the children of all the species for all time?

Systems thinking, social sciences, life sciences, bio mimicry and computing are all newer areas synthesised with Design to enrich the profession’s capability to address complex problems. Just as for Cretans, Syncretism meant reconciliation to combat common external dangers, Another one of Design’s virtues, lies in its

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[3](Edited by) Vijay: India is One. pp. 22. Sri Aurobindo Society, Pondicherry (2003).

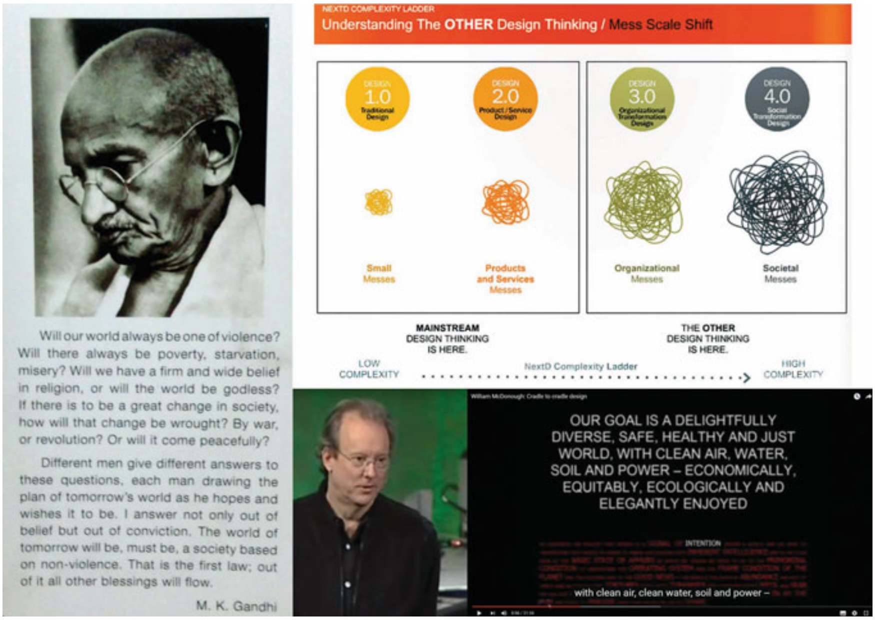

Fig. 3 Design for wicked problems (*Source* Gandhi Photograph, Author; The Other Design Thinking: https://issuu.com/humantific/docs/theotherdesignthinking & Cradle to Cradle TED 2005 Talk by McDonough, W.: https://www.youtube.com/watch?v=IoRjz8iTVoo)

syncretic abilities in both thinking and making solutions. These can be used to syncretise multi-faith populations to address urgent real world problems common to the entire planet whether environmental, medical, nutritional, political, economical, social, cultural, organisational etc. Our major issues are of the below three inter-related nature:

1. Scarcity (Food, Water, Sanitation, Education, Health, Clean Air),
2. Loss (Habitat, Environment, Jobs, Peace, Lives, Ethics, Accountability etc.),
3. Injustice (Terrorism, Oppression, Censorship of Free thoughts, Information and Ideas etc.)…

Design evangelists like David Kelley (Founder, IDEO), also sees design as a religion to be spread as urgently and creatively as possible. He refers to 'Design Thinking' as his *mantra.* The single most important virtue of Design according to him is 'Creative Confidence' [5]. He is not alone in thinking that creativity is invariably accompanied by endless possibilities and an ever-optimistic outlook in life [6]. Birsel, A., co-founder and creative director of a product design studio in New York, has ventured to teach non-designers how to create a meaningful life through her book *Design the Life You Love.* Her process, Deconstruction: Reconstruction™ makes life appear as a complex design problem to be solved with a designer mindset, i.e. 'optimism, empathy, holistically and playfully.' She is careful to point out that while she may be no 'psychologist', she is only offering tools for 'creativity and optimism' that emerge from 'introspection and understanding' of one's own 'constraints and parameters'. Thus through these values and virtues, Design *Dharma* can emerge as a meta-religion that binds world communities to address both material and emotional needs while allowing diverse conventional religions to co-exist and serve spiritual needs.

3 Manifesting the Design Dharma

3.1 Spreading Design Dharma

Information age has encouraged boundless creativity. People do not merely share about how to make artifacts but also steps on DIY Religion! A popular web tutorial site even shares a tutorial on 'How To Start Your Own Religion' which ends with this step, 'Now get out there and advertise, advertise, advertise!' [7]. Every religion or faith has required repeated promotion through people-friendly channels in order to gain acceptance. Much in the same way, if Design were to be preached as a world religion, what would be the media and channels? Like prophets and saints, Designers can engender holistic values of the *Dharma* within diverse communities by playing multiple roles as:

1. Design Practitioners who are a part of every sector-health, finance, governance, agriculture, tourism, environment, technology etc.
2. Design Educators creating or partaking in Design 'Hermitages' for advanced learning or imparting Design values as Itinerant Teachers making designing as commonplace as reading, writing and arithmetic for children and adults.
3. Design Advisors who can influence and facilitate powerful decision makers to value Design as an Ecological Solution for long term benefits.
4. Design Researchers who can build or collaborate with other domains to create Laboratories, Workshops and (Like Renaissance Artists) Academies that encourage learning by practice and push frontiers of the profession.
5. Design Volunteers who can create live or virtual Communities that democratise design and freely share values, ethics, tools, emergent ideas making design accessible to all through open source articles, forums, magazines, newsletters, toolkits, events and festivals.
6. Design Interpreters who can build bridges between the public and Design discipline by collaborating with Public Spaces such as museums/Exhibition Spaces and Public Open Spaces sharing Design Narratives, Epics, Legends etc. from India and the World.
7. Design Entrepreneurs who adopt their favourite roles whether it is an Artist, Inventor, Poet, Teacher, Storyteller, Engineer, Chef, Decorator, Saint or Farmer, while remaining sensitive to Design *Dharma*.

Unlike religious priests and monks who can gradually stifle religions with their dogmatic stronghold and fanaticism, Designers need not assume expert roles and dictate teams and communities about what to do. They simply need to be mediators and enablers of community action guided by their *Dharma*. Some efforts to make Design accessible to all can be seen in IDEO's openly distributed Human Centred Design Toolkit and their non-profit Ideo.org that allows non-profits and social sectors to use design methods and tools to find and solve problems iteratively. OPEN Ideo is a forum that regularly shares challenges for anybody to contribute towards issues that deal with preventive care, old age and even life after death. The Design Clinic Scheme for Micro, Small and Medium Enterprises (MSME), an initiative by MSME and the National Institute of Design (NID) lets designers and small businesses interact and apply design framework in their offerings and organisational structures. Carnegie Mellon's School of Design has relooked at their Design Curriculum to align with an evolved Design Ethos complementing the 21st Century. They offer flexible pathways for students to freely learn both core design values as well as skills and knowhow from other domains.

3.2 Ubiquitous Applications of Design

Design has been applied to unconventional socio-economic contexts that one is inspired to see how far Design ethics and values can impact other spheres of human existence. I was appointed as a consultant for an activist heritage communication project in the erstwhile French colony, Chandernagore, by Aishwarya Tipnis Architects. Juggling roles from an event planner, activity designer, live scriber to a web-design director, I worked with a team of young architects to co-create a participatory community engagement workshop [8]. With help from local student volunteers, playfully facilitated interactions could both spread awareness and capture aspirations and voices of a mix of citizens, about their town's past, present and future. Later, a web toolkit was prepared, enabling the client to custom-build an interactive website, that presents and crowd-sources media on the town's heritage. Late design legend and veteran, Prof. Ranjan, M.P. has dispersed the seeds of Design and attempted to redefine design to resuscitate and promote Bamboo Crafts in India [9]. Senior design professional, Balasubramaniam, A., has through design interventions, developed creative solutions in terror prone areas such as Assam, Nagaland and Kashmir for the UN. In the above two projects, the designer worked with a group of local artisans to develop products for universal use salable in global markets that helped revitalize both local skills, manpower and the local market. Kothari, D. [10], a young designer and Red Dot Design Awardee, shows how design can touch everyday life, with her 'closed loop' system of dynamic monitoring and pain free medicine delivery for diabetics. Contemporary designers are not merely concerned with life and its problems but also keen on exploring design for death. BIOS URN, Urban Death Project and Capsula Mundi (Fig. 4) are three variants of the applications of regenerative design. In all these cases, the philosophy

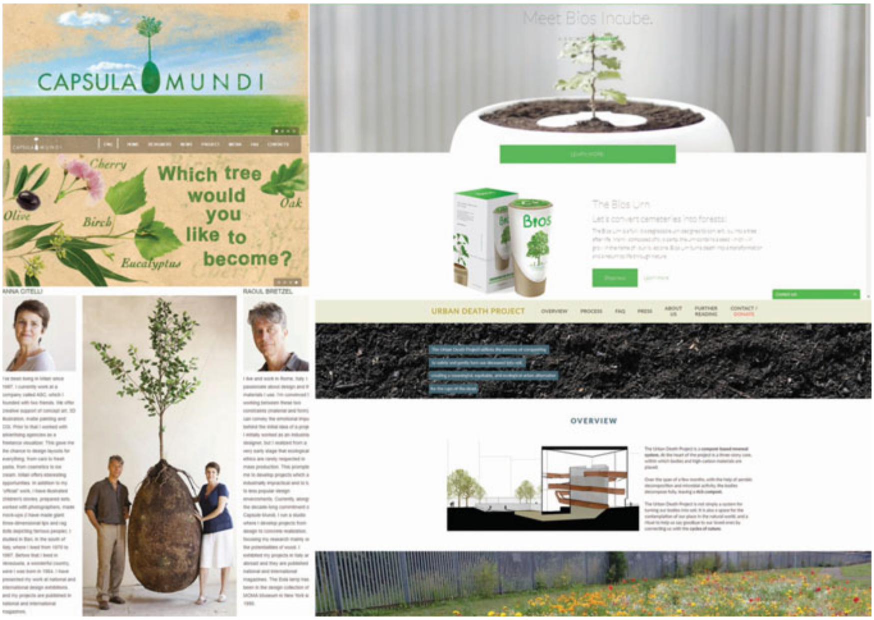

Fig. 4 Design for death (*Source* http://www.capsulamundi.it/en; https://urnabios.com; http://www.urbandeathproject.org/)

of death as a process of returning to earth and giving shape to new plant life seems to be an eco-friendly and novel way to bid farewell to a deceased dear one as opposed to conventional polluting and resource intensive options such as electric crematoriums and cemeteries.

4 Conclusion

To Design is to make a better experience, thus making a better world not merely in theory but through conscious practice, must be every Designer's mission. Design's innate values of optimism, empathy, creative thinking, playfulness, scientific tools and journalistic methods to investigate a problem from diverse view points, ability to systemically synthesize multiple contexts and iteratively offer ecologically sound solutions, can serve as crucial life skills for the future. Design by nature is syncretic. Design *Dharma* can be the essentials of what a religion does *sans* the dogmas and doctrines, which is to 'bind (people) together' into communions that are conscientious, compassionate and harmonious. These virtues make Design a Meta-religion which can foster cooperation between various religious paradigms for everyone's common good. The role of designers will be that of design prophets who can let themselves and others interpret design in their own creative way, but are guided to bind to the timeless spirit of Syncretic Design *Dharma*. Design is thus both within the 'parts' and outside as the 'whole' like a universal spirit that governs everyday life actions. This calls for relooking at the interchangeable relationship of the 'whole' and the 'part' vis-a-vis unity and design. But, true Syncretism to begin with, will have to be achieved within the domain of Design. The synthesis of various disciplines within and outside Design can transition from specialist Design domains (product, communication, interaction, architecture etc.) to a more unified, universal and generalist Transfunctional Design. Transfunctional Design could become the *Dharma*'s tenet, that every professional or citizen could acquire as a Way of Life. We might then have, quoting David Kelley, more 'Creatively Confident' and empowered citizens, in turn enabling progress through empowered global communions.

Acknowledgements This paper would not have been without the numerous web communities that regularly and freely share thoughts, philosophies and knowledge for public access by way of books, digital repositories and online forums. Special Thanks is extended to Mr. A. Balasubramaniam for his kind support in sharing about his design projects; to Prof. Ranjan De and Prof. Arvind Lodaya for their timely, critical and helpful guidance in articulating my thoughts better. I also extend my sincere gratitude towards Mr. Amaresh Chakrabarti for his patient cooperation through typical research obstacles.

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An Exploration of Design: Based on Pan-Asian Semiotics and Semantics

Tanima Bhattacharya and Joy Sen

Abstract Poet Rabindranath Tagore and artist Okakura Tenshin have collectively preached exploration of design semantics and semiotics based on Pan-Asian ideologies. The present paper attempts to establish their preaching based on an exploration of design in forming the un-built and built Architectural spaces. Design parameters integrated with nature and tradition are the major concerns in inseminating language of architectural expression. The paper attempts to establish the triad of Nature-Originality-Tradition, with a juxtaposition of heritage based creativity and innovation based high-end technologies. Finally, a conception of shared identity by the twin preachings through a confederation of art systems driven by a Pan-Asian viewpoint is identified as a major outcome of this paper.

Keywords Pan-Asian ideology · Triad of nature · Creativity and originality · Confederation/systems of art and design

1 Introduction

> All fine architectural values are human values, or else not valuable at all.
>
> —Frank Lloyd Wright

The paper aims to forward an exploration of design semiotics and semantics in the light of a Pan-Asian ideology hailed by Poet Rabindranath Tagore and Artist Okakura Kakuzo. In the first part, the paper deals with Tagore's idea of design parameters and aesthetics. Tagore has explained design based on the processes of complementarities amongst Nature as the upper part of the triad and tradition and

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originality being the two poles in the bottom rung. Nature stands as a culmination of design proto-types, ideologies and a deeper algorithm; whereas the other two represent creativity grounded on heritage as opposed to the lower rung, i.e., innovation based on high-end technologies. The thought is in alliance with that of artist Okakura Kakuzo.

To best substantiate the idea, the paper has subsequently explored the twin preachings in two concurrent parts 3 and 4. A living ecological laboratory by Tagore called the Santiniketan-Sriniketan experiment, inclusive of a major extension called the School of Design (Silpa Sadana); and instances of designs in Shinto gardens and the art systems of Okakura are the case studies. Thus, the paper argues that through an integrated triad of 'Nature-Tradition-Originality', much of modern design can be self-automated and self-sustained in a Pan-Asian continuum.

The paper also concludes by establishing the idea of human-nature interaction and the natural design based parameters through the twin set of case studies based on a Pan Asian foundation of Design.

2 Literature Review

To best arrive at an exploration of design guided by Pan-Asian Semiotics and semantics, a set of discussions are hereby forwarded:

2.1 Triad of Nature-Tradition-Originality
2.2 Pan-Asian Ideology of Tagore-Okakura
2.3 Aesthetics and Design parameters of Rabindranath Tagore
2.4 Tagore and Okakura: The triads of Complementarity

2.1 Triad of Nature—Tradition-Originality

Rabindranath Tagore, the poet of the nation and that of the world, realises that the beauty lies in the truth and simplicity of human life. In his ideologies, we can find the echo of a realization by Schumacher (1973) [1], '*Small is Beautiful*'. Following the realization, Nature based interaction with the art of livelihood can be regarded as beautiful and inseparably associated with the spirit of universal ecology. Design parametrics of nature based on simple geometric algorithm promotes the immanent beauty intertwined within simplicity. Rabindranath states that mans' sensory encounters with the environment are as important as his mind's enquiry into an inner mystery. He also emphasized the role of and outer societal needs to accumulate a basis to achieve the paradigm of self-sustainability.

On the one hand, as per Tagore, an interaction with nature will provide the scope of implementation of design semantics through micro consideration. On the other hand, Japanese design context of Truth, Beauty and Tradition can also be equated

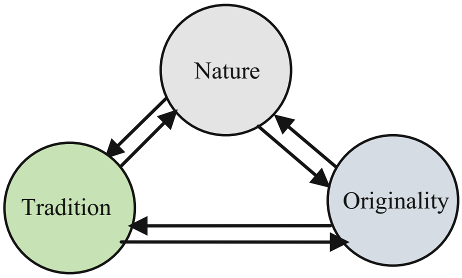

Fig. 1 The triad of nature-tradition and originality speculated by Rabindranath Tagore in Santiniketan, West Bengal (*Source* Concept adopted from Sen [9])

with the principles of Tagore's triad of Nature, Tradition and Originality (Fig. 1). Therefore, both the visions can be synthesized to understand the solution for the nature-human interaction based design problems and processes.

2.2 *Pan-Asian Ideology of Tagore-Okakura*

Tracing the solution for the design parameters based on an integration of nature-human relationship, the process of natural and cultural heritage can be traced in the concerns and writings of contemporary pedagogues. But the 'vision of unity' [2] has been proliferated by poet Rabindranath even before the issues of ecological at the global level. Rabindranath realized that built environs are complex ecosystems. In an architectural premise, physical-mental and spiritual interfaces interacting with each other are in the form of humans and with their environment. Understanding the ecology-based design and its evolutionary processes is one of the prime concern of today's technologically advanced planning and design systems, which can be readdressed through the shared concern of Tagore and Okakura based on Pan-Asian ideology-aesthetics. Therefore, 2 key features can be identified:

(a) Both Rabindranath and Okakura represent the dawn of an emergent Pan-Asian ideology in the early twentieth century with their quests. The ideology transcends the restless horizons of a material culture of the West, yet embodying the essence of its intellectual and imaginative features and dimensions.
(b) Both Tagore and Okakura believed that evolution can be achieved through the 'realization' and 'manifestation' of the 'Idea'. Especially Okakura postulated the idea of abolition of a nationalistic boundary in Asia through the thread of Buddhism and its integral concept of art and aesthetics. Even Okakura went on to state that during 600 AD. Japanese art history begins to sprout with the contact of foreign cultures thus, '*it is not impossible to say that our country's arts are almost entirely derived from foreign lands.*' Therefore as Okakura proclaimed 'Asia is One', he was mainly referring to Asia, from the East of the

Indus River, with India and China serving as '*the two great poles of Asiatic Civilisation*' [3]. '*Okakura viewed cross-cultural encounters to be a catalyst for change and saw his own time as a critical point where Eastern and Western histories were colliding, causing the evolution of both artistic culture*' [4].

Rabindranath Tagore's concept of beauty was inseparably connected with truth and simplicity. Tagore opined aesthetic sensitiveness, in the true sense, is a fundamental aspect of spiritual education characterized by a spirit of individualism, freedom, independence, peace and poetry. Likewise, Okakura was repulsed by Western society's obsession with the '*vulgar display of riches*' [5] and called that '*to be a part of the pageantry of wealth* [5].' As counteraction of this sense of showmanship, Okakura presents the ideology of simplicity and esotericism.

Kōjin [6], a Japanese scholar believed that Okakura has an inclination towards Hegelian dialectics. Following the dialectical exploration, Okakura grasped the history of Asia as art history seen as the process of self-actualization of the continent. From this sense of silf-actualization, Okakura brought into play the Indian philosophical notion of Advaitism (non-dualism), or the oneness of what is different and manifold. As a result, the expression called 'Asia is One' [6] emerges.

The book called 'Another Asia' (2007) [17] by Rustam Bharucha, states that the interaction with the contemporary artist, writer, intellectual and cultural practitioner provide immense solidarity of ideas about art-culture-aesthetics and design. With new ideas, visual semantics took a new turn. Okakura has cultivated a bond with artist Abanindranath Tagore, '*acquainted with Rabindranath Tagore, Swami Vivekananda, Sister Nivedita and others in the turbulent intellectual milieu of early twentieth-century Bengal* [7].' These interactions, therefore, acted as the catalysts to consolidate the idea of design semantics, based on ecological parameters.

2.3 Aesthetics and Design Parameters of Rabindranath Tagore

Rabindranath has preached the idea of unification of spirit of beauty and utility. For him, beauty lies in the truth of life. It is the crux of his realization of the omnipotent nature and a free evolving human spirit, who can nurture beauty in a proper way. Rabindranath Tagore always emphasized on the sensory perception of nature and envisaged the idea that physical and mental encounters with the environment around, was important for the development of the humanistic psyche.

According to Abu Sayeed Ayub (1992), the aesthetic philosophy in Tagore's emancipation is… '*In aesthetic experience, it is the objects which move into the background; attention shifts to and focuses on the emotional reverberations caused by them. Aesthetic delight is delight in self-expression—in this sense*.' In this respect, Hiriyanna (1954), an interpreter of Vedic aesthetics, opines that value

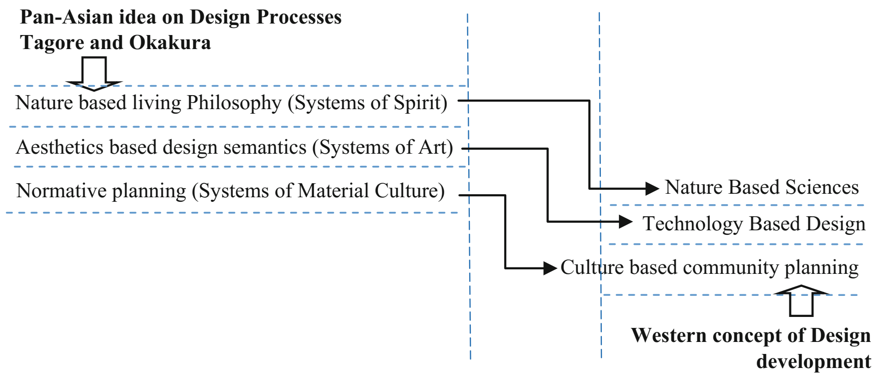

Fig. 2 Interaction of oriental and occidental features of design semantics

system and aesthetics are the means of temporary escape from the imperfections of the common life… where the 'Mind and the Body' find solace. If we look into the western principle that culminates in Lipps's (1897) words that aesthetics is '*an enjoyment of our own activity in an object*' followed by Worringer's (1912) formula: '*Aesthetic enjoyment is objectified self-enjoyment*' (see Fig. 2).

Tagore has successfully integrated and experimented his belief systems in Santiniketan-Sriniketan corridor. Tagore's concern for the principle of design-aesthetics manifested through the triad of Nature-Originality-Tradition is evident in the living experiment of Santiniketan.

2.4 Tagore and Okakura: The Triads of Complementarity

In Tagore's triad, there are three elements viz. Nature, Tradition and Originality. In Nature there are several features. The features are cycles, renewability which are embedded in the natural form and a subtle hint of something which is perennial and sustainable. Renewability means recurrence or re-evolving pattern of growth and contemplation. And by 'embedded in nature' we mean certain underline fundamentals of deep patterns, which are always operational under the surfaces of evolution and expression. Thus, the recurrence of both over a long period of time may be seen as a process of sustainability. Henceforth, the three principles collectively represent Tagore's triad (see Fig. 3).

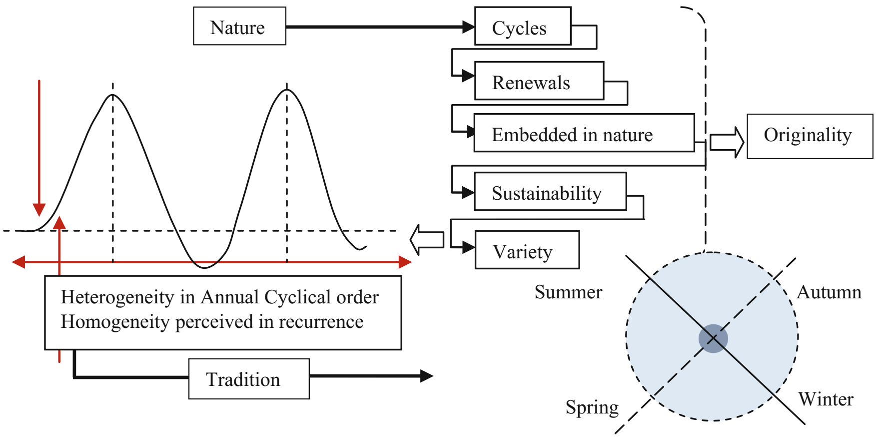

Fig. 3 The triad of complementarity tradition order and practice and the cycles of nature

3 Ecological Laboratories of Tagore and Okakura

The ecological experiments of Santiniketan can be discussed in two major parts, viz, one, the exploration of Santiniketan-Sriniketan experiments and two, the ideology of design processes operational behind the establishment of Silpa Sadana.

(i) **Santiniketan-Sriniketan Experiment**

Arthur Erickson said, ‘*Space has always been the spiritual dimension of architecture. It is not the physical statement of the structure so much as what it contains that moves us.*’ The architectural design of Santiniketan is based on the basic philosophy of integrating deep ecology with built environ. Consolidation of intangible with the tangible world is the key point to nature-based design semantics. Tagore in his adobe of peace Santiniketan has probed into the idea of design semantics that is based on individualism, freedom, independence, sustainability, uniqueness and peace, which is also a path shown by Okakura. Figure 4 delineates the physical boundary of Santiniketan-Sriniketan corridor buffered by the river Kopai, naturally attributed a scope of carving of an ecological niche and sustaining the farmstead rhythm of the seasonal cycle of Birbhum, Bengal.

Tagore perceived Architecture as an array of affordable low-cost structure that would serve as a model house for poor villagers. Shyamali built in 1930, (Fig. 5) for example, is a form that has been made as the experimental model of a modern affordable structure. The structure would naturally create a shield from the heat of the barren landscape of Birbhum, and will also preserve the heat of the room inside during winter. Punashcha (Fig. 6) built a year later (1936) was erected as according to the directions of Tagore, on the Eastern side of the existing structure of Shyamali.

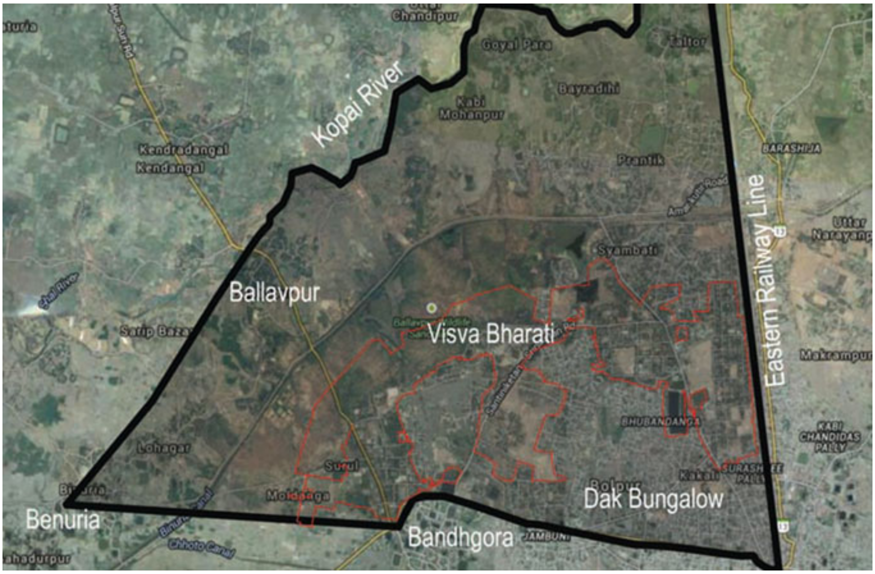

Fig. 4 Sriniketan-Santiniketan, Birbhum (*Source* Revised Land Use & Development Control Plan for Sriniketan-Santiniketan Planning Area; Developed by IIT, Kharagpur, 2015)

Fig. 5 The front view of the experimental erection of Shyamali by Rabindranath Tagore

In a way, Santiniketan can be equated with a lab where Tagore has experimented with all his ideas to create nature-based self-sustainable habitat. The next building is Udichi (built in 1938), as a physical manifestation of Tagore's thoughtfulness with the house stands on four short pillars covered by latticework Santiniketan (Fig. 7).

Maharshi Debendranath Tagore, the father of Rabindranath Tagore, declared: '*Apart from worshipping the Formless, no community may worship any idol depicting god, man, or animals…The sermons given here will be such that will be appropriate to the worship of the Creator and Father and will help in ethics, benevolence and brotherhood…*'. Thus from the very moment of its initiation,

Fig. 6 Punascha at Uttarayana Complex, Santiniketan

Fig. 7 Udichi at Uttarayana Complex

Santiniketan formed as a space devoid of any nationalistic barrier; and somehow, the spirit of Pan-Asian ideology hailed by Tagore and Okakura gets a scope to be implemented practically. Thus, in the architectural design process of Tagore, one experiences a transformational sequence initiated at the physical level, through the layers of the mental and the cognitive and finally reaching the highest step which is the vast, the truth in the natural and cosmic (see Fig. 8).

(ii) **Integration of Japanese Elements in Birbhum, Bengal**

In designing the nature based built and semi-built spaces; Rabindranath infused elements taken from aesthetic principles of Japan as well as from the variety of

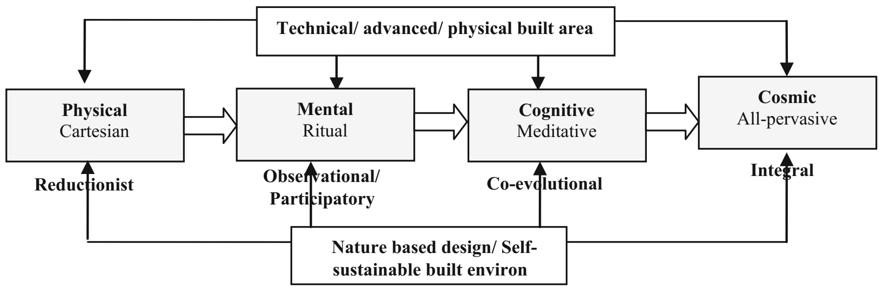

Fig. 8 Conceptual diagram showing the transformational stages from a mere physical built environ to a self sustainable cosmic level by incorporating nature based design parameters (*Source* Sandhi Brochure, http://www.iitkgpsandhi.org/images/SandHI_Abstracts.pdf)

Indian continent. Two key elements of Design can be retrieved from Tagore's approach.

(a) Deep Ecological systems viewpoint
(b) An inclusion of variety in design process

(a) **Deep Ecological systems viewpoint**

During the period of Rabindranath Tagore (1918–19), the architecture in Santiniketan has achieved a distinct character. It shows influence of classical Hindu-Buddhist temples, *chaityas* and *viharas* with some major influences from far-East in case of interior and wood work. These influences were already established in the statement of Okakura, that he believed, India, Japan and China shared the backdrop of same ethnicity. Particularly in terms of deep ecological or religious connection of Buddhism they shared the same paradigm. Architectures of Santiniketan also manifest inspiration from Mughal, Sultanate architecture, Rajasthani references to ancient civilizations along with decisive experiments with local rural architecture.

(b) **An inclusion of variety in design process**

Rabindranath, always eager and extremely receptive towards cross-cultural ideas and methods has invariably included artists and scholars in his travel troupes to the foreign lands. Specifically Rabindranath's connection to the Eastern Asian countries inclusive of Japan executed a great impact on his ways of seeing, Japanese precision, subtlety, simplicity, balance between positive and negative space, originality, elegance and asymmetry had left an undeniable impact on philosophical orientation of Rabindranath that can also be reflected in art and architecture of Santiniketan.

(iii) **School of Design or Silpa Sadana**

Sriniketan also forwarded a distinct step in the field of rural reconstruction. In 1907, Rabindranath sought to expand the school's relationship with its neighbouring villages of the Santhal tribal community. The school, from its conception, aimed to combine education with a sense of obligation towards the larger community. Tagore was well aware of the need of integration of '*two way knowledge communications between our traditional indigenous knowledge of the village folk and the new progress in technological area*, [8] to reclaim the parity in nature-human relationship. To best arrest the achievement of Silpa Sadana Tagore expert Banerjee [8] said, '*Both Rabindranath and Vivekananda, two very finest renaissance minds of India, had realized such humanistic, spiritual and scientific convergence of India's own living design—that India lives in village. Rabindranath at Visva-Bharati very wisely stressed upon revitalization of these aspects through Kala Bhavana, Vichitra Karusangha, Silpa Sadana, initiatives which were an essential part of rural reconstruction through co-operative movement*' [8].

4 Okakura's Probing for a Better Psycho-somatic Experience

Alike Tagore's Santiniketan, the artist and art historian Kakuzo Okakura didn't get the opportunity to experiment with the ecological parameters of planning and built environ in a grand manner. His ideologies get consolidated in the basic design semantics of rural-traditional Japanese architecture. Okakura has formulated his idea of ideal built form in his *The Book of Tea* (Tokyo: Charles E. Tuttle Company, (1904) 1956). Though Okakura is not an architect, but he has shown his concern with full conviction to retain the connection to the traditional roots. He has specified design principles about the making of *Sukiya tea-houses* that need to be built in isolation to contemplate nature. In expressing the principles, Okakura integrates design semantics based on individualism, freedom, independence, sustainability, uniqueness and peace like Santiniketan of Tagore. Okakura's description consist the basic principle of individualization that can be regarded as probable influence of individualistic societal frame of United States. According to him,

> The tea-room is unimpressive in appearance. It is smaller than the smallest Japanese house, while the materials used in its construction are indebted to give the suggestion of refined poverty. Yet we must remember that all this is the result of profound artistic forethought, and that the details have been worked out with care perhaps even greater than that expended on the building of the richest palaces and temples. [3]

The principle implies Okakura's inclination to retain the simplicity of Japanese tradition to imbibe nature as an aspect of livelihood. This built form of the tea-house also relies on the availability of the local materials that attributes pliability to the structures.

> The tea-room is not only different from any production of western architecture, but also contrasts strongly with the classical architecture of Japan itself. [3]

Okakura's design strengthens the bond between human and nature by elevating the space of dwelling from a physical entity to a space of contemplation. Here Okakura encourages to extract the pure beauty lies within simplicity (Fig. 9).

Fig. 9 Different views of design aesthetics of Tea house and Shinto Garden, Kyoto, Japan (*Source* Author)

5 Conclusion

The paper brings to light a living philosophy of design seen through the lens of a Pan-Asian ideology hailed by poet Rabindranath Tagore and Artist Okakura Kakuzo. Rabindranath's idea of design parameters and aesthetics based on the triad of Nature-Originality-Tradition has transformed design to visual parameters of semantics and semiotics in nature-human relationship. Okakura's work also represents the Japanese side augmenting the very same transformation. Japan and India are two of many Asiatic representations earmarking a system of Asian Art and design within one frame. Tagore has substantiated his ideas through the experimentation of the living ecology of Santiniketan- Sriniketan. His design objective is to best revive rural design technologies in contemporary format. Reciprocally, Okakura's ideology also shaped up the design semantics of Japanese Sukia Tea houses and Shinto gardens of Kyoto.

The application and spontaneity of the Tagore Okakura principles are even valid today. To begin with, artist Abanindranath Tagore has re-discovered the integral semantics of art and aesthetics into a system of visual art and design of Asia. Abanindranath has integrated elements of art of Asia as calligraphy, wash techniques and the style of minimization. Thus, his ideology grounded in the conception of a shared identity of the two thinkers driven by a Pan-Asian viewpoint has triggered the initiation of the wider Bengal School.

As an extension of the pan-Asian confederation, Bichitra Club was founded by botanist Rathindranath Tagore in 1915. The club activated a melting pot of intellects from different background, ranging from literature to art; drama to music; and of intellectuals from different national background namely, India, Japan, and England.

The reflection of an organic order in the contemporary works of Frank Lloyd Wright and Richard Neutra has been suggested by the historian Dmitri Tselos. He first identified that the Nippon Tea House from Japan has a possible influence on Frank Lloyd Wright, suggesting that the low-pitched double roof forms of the Prairie Houses as having similar forms as the teahouse roof (Nute 1993 [18]). Not only Frank Lloyd Wright, in 1954 Walter Gropius, the founder of the Bauhaus visited Katsura Detached Palace and was so struck by it that in 1960 he co-authored *Katsura: Tradition and Creation Japanese Architecture* with Kenzo Tange, augments both an application technology in design and design as a renewable process embedded in Nature reflects the ancient Asian ideals.

The contemporary product design parameters proliferated by Kyoto University and a reciprocal system of National institute of Design, India, have still followed to an extent the design parameters shared by Tagore and Okakura in their preachings. Thus a power of the shared identity of the twin preachings representing the universal Pan-Asiatic ideals of Design is still evident and resurgent.

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Cultural Construction: Design Aesthetics, Semiotics and Semantics Associated with Masks in Namghar—The Study of Its Design Aspects in the Island of Majuli, India

Charu Monga and Amarendra Kumar Das

> It was as if he had two faces, one of utmost calm, one of furious action and he wore both with ease. He was like the animal whose face he wore, able to sit in silence for hours, without moving a muscle, then flying like a raging storm into battle, returning again to perfect calm when the fight was over.
>
> −Kaoru Kurimoto (1953–2009), *The Leopard Mask.*

Abstract This paper concerns the application of visual ethnographic research within a field study and the ways in which it was developed and applied as to a range of visual documentation method settings, for an illustrated applied art intervention purposes. Majuli Island located in the banks of Brahmaputra River is the home to Social-cultural institutions, Satras. These Satras are in turn origins of novel craft making practices that are often utilized in cultural performances that occur in these social-cultural institutions. One such practice that is widely known is making of mask. Visual method processes have been used as an adjunct means to record oral, images and kinetic energy data as representations of characters, individuals, and groups of mask making culture. This Visual Ethnographic research generates an artistic interaction between visual designers and mask making artisans in the Island of Majuli India, in-and-out studio process. Its insights bridge the physical experience through free hand drawing to a digital output—in a graphical form. This visual ethnographic research aimed exploring and reflecting cultural phenomena in artistic method, but behind the scene, this paper seeks to arouse the issue of cultural loss of masks and intellectual potential in mask making tradition of these artisans who live in an Island separated from the world.

Keywords Mask making tradition · Namghar · Design intervention · Visual ethnographic research · Design thinking

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1 Introduction

The Majuli is the one of the largest river island in north-eastern state of India, Assam. It resides in the lap of the Brahmaputra River. Majuli is known for its bio-diversity, ethnic practices of the tribal communities, extensive network of social cultural institutions, Satras. These Satras are structures representing Vaishnavism tradition, which is culturally precious with various forms of dance, music, handloom and crafts. One of the preciousness associated with these Satras is the Majuli's Mask making tradition, that needs immediate attention, since this has not received due attention. Mask is used in Ankia-nats; musical dramas, incorporating different categories of songs created by Shankardeva, the founder of Satras. Since, due to urbanization and also threat from erosion, the massive land of Majuli is shrinking and therefore, there is a critical need at this time to find an alternative for preservation of core tradition of Satras, which is Mask making [1]. In next subsections, the discussion is made on history of mask making. Culturally, mask is a part of a storytelling, a semantic content of narrative, mythos, and an emotional effect. This mask is a universal cultural phenomenon, which has been utilized from ancient times to early modern as well as Renaissance periods. These are equally prevalent in both Western and Eastern cultures. Despite modernization, it still continues to be a healthy part of contemporary culture. Masks vary from place to place, from sub-culture to sometimes small communities, such as native of Majuli. Even though masks have been known from ancient times as understood from art work in countries such as Spain, China, India and France, modern society still has an intense use for them.

Various cultures around the world including Indian, Chinese, Japanese, African, and Australian, all have their own indigenous masks. In all the cultures, the masks have been often used for ceremonies, rituals, arts and theatrical performances etc. Functions of masks can vary from the sacred and spiritual to the comical and mundane. One can define mask as a tool or object that is worn to help conceal one's own identity [2] by its own features to establish another being. The identity and design of mask changes, but one thing that remains common is the feature of hiding and revealing the mask user's identity. Psychological perspectives relate to mask user and who watches it. Robber's mask can be very convincing for bank tellers; Mask affects Kabuki theater audience, people in the Carnival of Venice, or Indian community believers in religious rituals. Israelis celebrate Purim, a mask festival that commemorates the salvation of the Jewish people in ancient Persia. Paulo Coelho (B. 1947) Brazilian lyricist and novelist claim: "*We all wear masks at some time in our lives as a part of human nature: we feel to hide excitement, fear, anger, sadness, or just sometimes manipulate others. The reasons behind the different masks that people wear vary considerable, but they can be both positive and negative*". Carl Gustav Jung, one of the founders of modern psychoanalysis, classified four levels in human individuality:

First, Persona—Derived from the Latin word PERSONA. The origin of this word is in PER-SONO, meaning "sound" or "lead" voice. The mask is the tool through which the player's voice was heard on Greece and ancient Rome. Since, as is well known, extended meaning of the word and it refers not only to the theatrical mask, but the persona mask; does not cover a personality, but become the same.

The persona is human interface towards the outside world, different circles: intimacy, family, friends, work, etc. Repressing persona personality traits and weaknesses-abhors conflicts, airing the best "design" of his traits and messages it to his own circle: wise, strong, cool, sensitive, leader, creative, producer, connector, artist, etc. A woman can have set of varies—nuances—masks in her chosen "persona", toward her daily functions: for her baby, grandchild, beloved, husband, parents, sister, brother, best friend, friends, boss, colleague, doctor, stranger. These Nuances are the role presentation all in one human being,

'Mask' it: differ people's individuality by behavior patterns, cognition and emotion. Persona is a form of protection, the mask that individual wear every day, present his/her personality to the world, pretending to be who he/she is.

Second, Inner mask of Anima/Animus—the opposite gender qualities and attributes of the psyche; represent the "true self".

Third, the Shadow—the dark side of the psyche; consists of repressed, memories, ideas, emotions, weaknesses, desires' instinct; represent wildness, chaos, and the unknown.

Forth, The Self—unification of the conscious and unconscious; individuation and self-actuation; contains all aspects of an individual.

Masks as cultural objects are not only found to vary in their appearance but also found to vary in its use and symbolism. For example, masks can be used as object to be worn on face for concealing the wearer's face, headdresses worn on top of the head or even detailed body painting or facial makeup.

Throughout the world, masks are being used in rituals and theatrics traditions for expressing power as a feature. This dual usage of mask in ritual and theatrical traditions generally overlap and merge but still provide a useful basis for categorization. In the old Greek theater, the mask images took crucial comedy and tragedy roles. Whereas, masks have been also used in social and religious rituals for representing spiritual or legendary figures and in some cultures, it is believed that mask wearer may possess the characteristic of character [3] (Figs. 1 and 2).

Fig. 1 Majuli Island

Fig. 2 Satras in Majuli

2 Background

2.1 Culture of Majuli Island

Majlui is known as the cultural capital of Assam for 500 years. Satras set up by Srimanta Sankardeva, a 16th-century social reformer has been home of cultural preservation of antique objects, masks, jewelry, writing and other items of cultural significance. These Satras were formed as a result of medieval-age Neo-Vaishnavite movement. These Satras are social-cultural institutions and are center for various social gatherings (meetings on village decision) and also cultural festivals such as Raas festival. Almost, every single person on the island is involved in this festival. The festival is celebrated by depicting the life of Krishna. People from large distances come to this island to celebrate this festival including a significant number of expatriates. The Satras are also home of origin of novel art and craft traditions. One can still observe the craft practice of mask-making and boat making in Natun Samuguri Satra and Kamalabari Satra respectively.

2.2 People of Majuli

Deori, Mishing and Assamese are the local inhabitants of this place. Mishing tribes immigrated from Arunachal Pradesh. In addition to these tribes, there are Sonowal Kacharis tribes live there. Mishing, Assamese and Deori languages are commonly spoken by people of this island. People in Majuli rely on handicraft and pottery to earn money. The technique of pottery in Majuli is similar to that found in ancient Harappa Civilization. Pot in Majuli is generally made of clay (beaten) and burnt in kilns at usually very high temperature. However, due to modernization and also threat due to erosion and rat race of livelihood, there is threat of loss of this indigenous identity.

Fig. 3 Lotokaimukh in Majuli Namghar

Unfortunately, due to modernization and also changing lifestyle, the commercial values of these products have become minimal. Among many of crafts, Mask Making is one of the most famous traditional crafts that is still practiced in this island and especially practiced by the Bhakats here in Sattras. Nutun Chamaguri Sattra is known worldwide in making exquisite masks. Mask making is an integral part of Sattriya culture. These masks were conceptualized as a tool by Shri Shankaradeva to design and depict the characters of Srimad Bhagwat to the bhakats. Masks helped to provide a physical form to these characters and also simultaneously help people to get associated with the stories related to mythical heroes (Fig. 3).

Many researchers from social background has urged to preserve the uniqueness of people, whose cultural forms are not affected by modernism [4–7]. The handloom skills of these tribes are also globally famous. There is clear transition in material change in housing from traditional bamboo and mud construction to concrete. The artists or people of village gather at a place called Namghar, which is a nucleus of Satras. They gather frequently to sing and pray. After the rituals, villagers gather together in these places for discussion on issues related to auctioning of fishing rights, financial and other topics of significance to whole community. The inhabitants of this island are expert navigators by boat. This is mostly visible during the monsoon season, when the water is highly turbulent in mighty Brahmaputra (Fig. 4).

2.3 Types of Masks

Three types of masks that are traditionally made by craftsmen in Majuli are (1) **MukhMukh (face masks)**; (2) **Lotokai Mukha** (face masks but allow movement of lips, eyes, hands etc.); (3) **Cho Mukh** (whole body mask). Cow dung being a light material is used for making these masks. The height of these masks can be from 2 to 5 m high and the performer can wear it above the waist. This huge

Fig. 4 Mukh Mukha Mask

structure of masks helps to display and enhance the aura of the certain character. The huge masks are generally tied up to the body of the performer with ropes. This helps to keep mask intact during the performance when artists flex its body. Sometimes artists make these masks in separate able parts also experiment in adding rubber band for mouth movement, use of various fabrics and materials to make the body of the mask. As the requirement of the play goes these craftsmen are capable to add or subtract the materials in the body of the masks.

This traditional mask making tradition of Majuli is practiced by one family only in Majuli village. In Nutan Chamaguri Satra, **Sri Hemchandra Gowswami** is the main craftsmen have trained few other artists in his village to carry forward this old tradition. Most of the mask makers belong to Kayastha caste and practicing this tradition. These masks are used in performance referred as **Ankiya Bhaonas**. This is a Vaishnavite one act play, where victory of good over evil is depicted via mythological play illustrated in Vaishnavite scriptures. These masks are also used in some phases of **Raas Leela**, a theoretical performance. This particular Satra has a history of 236 years of making masks. There are various different characters used in these performances like serpent, demons, gods etc. Masks were worn to express the aura of these characters. Most of the characters are been played by men only as the performance is quite time taking and sometimes the costumes and masks are very heavy. For manufacturing of masks, the frame is prepared using bamboo and spring first. This is followed by colouring and clothing from master craftsmen for final finishing.

2.4 Making of Masks

In Assamese tradition the masks are called '**Mukha**' and the mask maker is called '**Kahanikar**' (Figs. 5, 6 and 7).

Fig. 5 Making mask with bamboo strips

Fig. 6 Artisans painting masks

The local bamboo name **Jatibanh** is generally used to make the frame of mask. For preparing the frame, the bamboo is cut into pieces or strips of about 2–3 m in length. For protecting bamboo from insects attack and also to increase flexibility and durability, these bamboo strips are dipped inside the water for a period of 5–7 days. The machete tubes are then longitudinally divided into pieces using katari (knife). The base of the mask is then made by weaving the bamboo strips in an open hexagonal pattern. It is similar to the weaving basket technique traditionally used in other parts of Assam. This masks is referred as **Lakshmi Sutra**, a Hindu goddess for prosperity and health, by mask makers. It is because famers in these island keep Assam paddy (respect as abodes of goddess Lakshmi by Assamese people) into a basket weaved in a hexagonal pattern. This particular hexagonal pattern is called 'Tom'. The weaving sutra of this particular mask is called as 'Lakshmi sutra'. Cotton cloth dipped in Kumhar Mitti (a special mix of water and clay) is used for covering the weaved base of mask. This is followed by dipping the entire masks in mixture of clay, cow dung and water. It add prominence to the mask by giving it shape and feature. This particular procedure is known as Chehera Dia. It means adding the appearance.

In order to get rid of water, the mask is then dried in the sun. As the mask get drier, it simultaneously scraped with a 'Karani' (bamboo scraper). This is later

Fig. 7 Masks of Majuli Island

followed by coloring and detailing of the mask. Detailing of masks are done by adding ornaments, mustache and final touchups. Also adding the hairs made up of jute ropes and coloring it naturally. In old days craftsmen use to colour with natural dyes, but now they use already available colours in the market as quite tedious and time consuming to make the natural colours. Also bamboo tubes were used to store the colour made in different sizes. Brushes use to be made up of pigeon feathers or bamboo sticks. These were also modified by adding goat's hair as bristles. The broad brushes used for coloring are made by using the jute fiber to bamboo stick. Now it been replaced by synthetic brushes available in the market. Coconut bowls were used for mixing the colour (Figs. 7 and 8).

2.5 Material Used in Masks

Based on frame material, there are two types of masks such as bamboo and paper. The procedure mentioned in previous section describes about bamboo framed masks. In this section, we mainly describe the paper made mask.

Paper: Clay cast is generally used to prepare Paper Mache. The shape of clay is guided using a knife. The gum used for sticking paper is made from natural material (crushed seeds of Bihmana or Kendu). These are then soaked and casted on clay

Fig. 8 Masks of Majuli Island

cast. **Coloring material is prepared by powdering** Hengul, haiatal, Neel, and Dhalmati on a brass plate with stone. **They are then applied on the mask**. The brush **for coloring** is **composed of** cat's hair **stick to a sharp edged** bamboo. **For storing**, the colors and dyes are **generally** stored in small bamboo **strips (enclosed nodes)**. **Headgears are generally made of these paper masks**. For other parts **of mask mud, bamboo and cloth** are used. **Masks depicting characters of** Gaduda, Brahma, Dhenukasura, Batsasura, Hanuman, Hansa, Maricha, Bakasura, Ganesha, Aghasura, Jambuban, JatayuKumbhkarna, ten headed Ravana, Subahu, Putana, Chakravat, KaliyaNaag, Taraka,,Baraha, Nar Simha etc. are generally made of this approach. Masks for Krishna, Lakhshmana Rama, ar**e generally** not made. **On the day of performance, these masks are considered** as the God's incarnation. Apart from these **masks**, swords, Dadhishal, rathas (chariots) for war, Gada, arrow, **Bow**, axes, Chakra, Vajra, Head gear, Trishula, Nupur, **horses and** full sized cow, **are also prepared as per the need of storytelling** (Fig. 9).

Fig. 9 Mukha

2.6 Other Material

Mukha artist Sri Hem Chandra Goswami demonstrated the art of making masks at Chamaguri Sattra in Majuli, Assam. The masks, which usually take 10–15 days to make, are made from locally available materials like bamboo, cane, cloth, clay and vegetable dyes. The frameworks of the masks are made by joining the loosely woven bamboo strips into a desired shape of the face. This is followed by covering the frame in layers with a cotton cloth dipped in a mixture of water and mud. This is then dried in a sun. For shaping the eyes, ears and other features, a mixture of clay and cow-dung paste is applied on bamboo pieces. For hair, eyebrows and other accessories, jute or cat's hair on pointed bamboo is used. For smoothing surface and filling mask, 'Kordhoni' (smooth piece of bamboo) is used. After this, the mask is ready to be painted earth and vegetable dyes. The most commonly used colors are red, yellow, blue and green (Fig. 10).

3 The Ethnographic Illustrative Method

3.1 The Visual Ethnographic Method

3.1.1 Aim and Objective of the Study

The visual ethnographic study had two main objectives.

Fig. 10 Garuda Mask

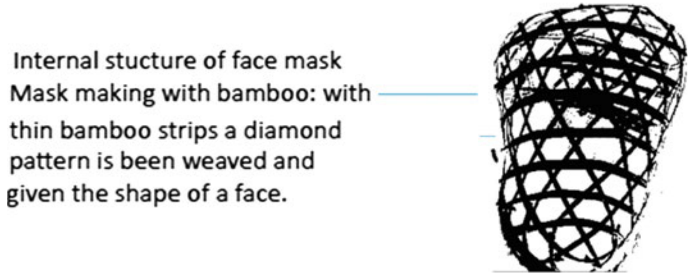


Fig. 11 Mask making with bamboo strips

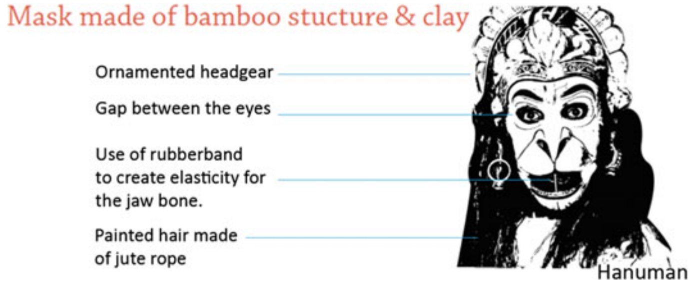
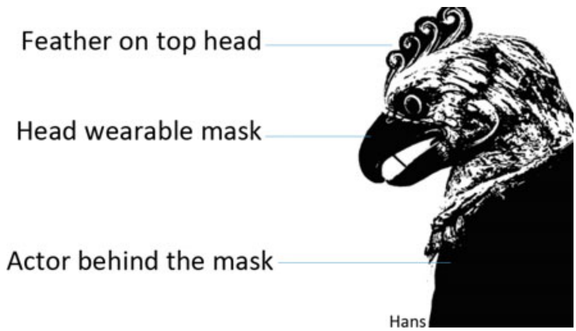


Fig. 12 Analysis of Hanuman mask

– To study and document the process of mask making in Majuli Island and the major changes over time with regard to material, style and the use of mask.
– Follow the mask making process by free hand drawing and filming and propose a design intervention in terms of a study manual, and an interactive video game (Figs. 11, 12 and 13).

Fig. 13 Analysis of Garuda mask



3.1.2 Research Questions

- How can the vanishing masks of Majuli island be preserved and create awareness regarding these masks?
- Are masks of Majuli really effective in terms of communicating mythological values, ethics in present scenario or will remain as a cultural object?

3.2 Structure of Masks of Majuli

The initial structure of masks of Majuli is been made with sliced bamboo strips, which has been cut into various pieces. With the help of these pieces the skeleton of the mask is been made. The mask maker checks the mask by fitting it in his own head and does the re-touching over the base structure. It's been weaved in a star structure. Firstly, the skeleton structure with bamboo strips is been weaved and then on top of that a layer of clay or cow dung is applied. Then craftsmen give the details to the structure like nose, ears, eyes etc. Small pieces of thin cloth are been soaked and applied over the mask with gum and dried to give it a stiff feeling to the armature. Hengul, neel, hiatal and balichanda (mica) is been applied for accentuation. Various shapes are been given to the masks like adding a beak in Garuda mask, headgear in the Hanuman mask etc. As basic structure is an important part of the mask making process because it has to be wore by the performer and his head should fit into that bamboo structure with that easy movements should happen without any difficulty, open spaces should be given for eyes and nose. The basic casting technique is been used to make the structure. There are also paper mache masks, which are lighter in weight but the same casting technique is been used. The mask is made till shoulder as it should look like the part of the character and with that detail has been given to each corner for example neck has the jewelry part etc. All the natural material is been used to make the mask.

3.3 Methodology

The methodology of the study was developed based on these objectives. The study used ethnographic methods. Data was collected in terms of digital documentation, interviews, understanding the process and materials. Another stage which consisted of a visual survey of mask making artists. A shooting team used to collect visual information without any script preparation. The team also shot, photographed and filmed the process. The details of the sample study were analyzed later in the studio. Interviews of mask maker, his disciples and Satra Adhikaris (gathering place in assumes tradition) has been taken, Raas Lila and Bhaona performance has been documented which was around an overnight performance. Change of colour palate in the performance has been noted and analyzed. Visual semantics has been analyzed on the bases of collected data.

3.4 Research Processes

Processing this kind of visual ethnographic research, a formulated method is a very unexpected procedure. Nothing could be planned and scheduled not even roughly. Making of these handmade masks and using them in performance is quite tedious process. The artist has to take care of the colour palate and dimensions.

Making of the manual: We have studied the mask making process from planning to prototyping it. From making the bamboo weaving structure to adding layer of cloths, clay and then giving the structure a proper shape. There are some masks like Ravana's in which multiple heads are attached to one mask. In these kinds of masks pre-planning becomes very important. Initial documentation of the process is been done also recording of the Bhawona and Raasleela performance is been done and studied to understand masks significance in there society. Interviews have been taken of the Satra adhikaris, audience, who came to see the overnight performance for continuous three days. Observation is done in terms of how they react to the mask performance. To keep the audience engaged into the performance, color palate is been changed in every scene also dialogue delivery is been modified as the performance was moving ahead. The team digitally documented the masks and the performance also scanned some masks to analyze the colour palate with that measured the scale of the masks and made good number of drawings to record and understand the people and places of Nutan Chamaguri Satra. We came back to our studio with the data collected and started analyzing them in terms of size, colour palate, dimensions, making process, analyzing the interviews etc. During analysis process we found some set of commonly used colours in masks like red, yellow, blue and green. Then a structure is been made with the help of measured drawings to depict the dimensions of the mask and by using step-by-step process the manual has been created. After documenting the mask making process in DIY manual its been taken into another level by introducing it in terms of a video game for children's to understand the masks and narrative associated with it. In the later stage as the child can make the mask by playing this game, they can take printout of the masks made by them and assemble it into a wearable mask. We designed three main process milestones strategy: Non Documentation Research, Documentation Rushed and Artistic Intervention.

3.5 Non-documentation Research

This phase was free of any research method. Just staying with the tribe artisans, and exploring the rituals, materials, and techniques, during the mask making tradition and during Bhawona performance. Also, we followed the preparation of material, the coordination among the people and capturing the intricacy of ritualistic process. Also, we studied the materials and processes which go into mask making.

3.6 Documentation Rushes

Setting research design process and close interaction between researchers and mask makers before and after the performance; setting place of performance, stage, still shooting, filming, taking visual notes, deep interviews with mask makers and their families; and also, recording the mask making technique with the help of sketches.

3.7 Design Intervention

Analyzing the data collected during field research in making of the manual. Understanding the process and translating it into design blocks. Converting filmed rushes, snapshots to a visual scenario. Drawing the shooting frame by frame to illustrative format. Digitizing illustrations and masks, their patterns, colours, proportions, scale, form etc. final details and overall look. Overall, getting the real essence of aesthetics values of their tangible interactions (Figs. 14, 15 and 16).

4 Conclusion and Observations

The traditional identity of mask making has taken an upgraded turn over the period of time. It has been used in various cultures to depict various identities. Like in Indian context Modi's (leader) mask in rallies worn by crowd depicts support of that particular leader also the multiplication of these masks shares a strong message. Mask used in Halloween depicts a scary and creepy character but it's been associated with particular culture. It's really amazing to see association of all these masks to depict different identities. It carries history and its effectiveness in people's lives. The film, learning manual, game and the DIY kits depicts and carries the

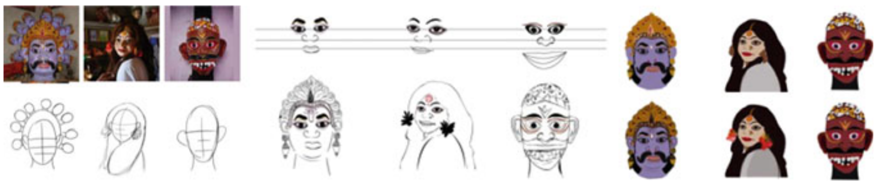


Fig. 14 Analysis of Masks on the basis of design elements

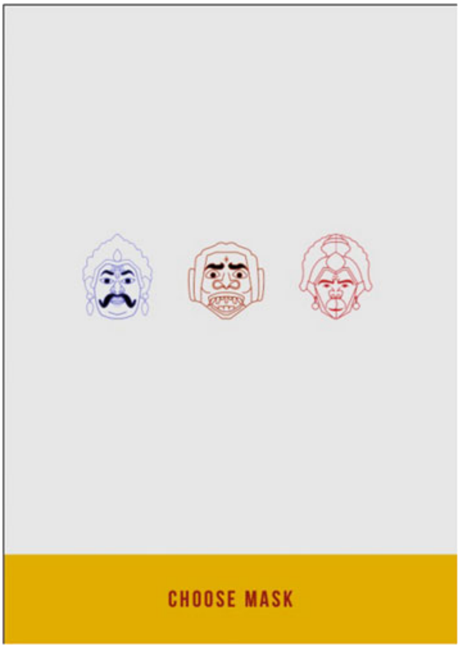


Fig. 15 Mask of Majuli game interface

Fig. 16 Printed masks

cultural identity and effectiveness of the particular kind of masks also its associations with the society. We wanted to make it effective and bring awareness among the students about the culture of Majuli Island also to show how it survived after a huge struggle. The study initially explored the use of mask over time in the area of Majuli Island and the methodology used was descriptive and qualitative. Also major turning points in preparation and the use of mask is been studied through descriptive method. The history and literature of Majuli Island as well as masks has been studied. Digital documentation has been done. Characters, colors and design elements have been identified. Interview with the mask makers, Satra Adhikaris and audience has been done to understand the in-depth use of masks. Characters of Raas Lila has been studied and an overall understanding has been developed as these masks is also been used in Bhawona performance. Later design intervention has been concluded by a DIY manual and an interactive video game and tangible masks.

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Bollywood on Television: A Backbone for Creating Social Connect with Indian Audience

Paritosh Singh and Saptarshi Kolay

Abstract Television has always been an integral medium for consuming content and connecting with audience across the globe. Along with its increasing reach to different sections of the society, the television as device keeps evolving with the technological advancement. It is no more just used to showcase the broadcasted content. The expansion of internet connectivity is setting up a strong ground for innovations like Smart TVs. The initial part of this paper explores the potential domain for Smart TV applications (apps) which can establish its better connect with India television audience. The surveys are conducted to understand the mental model of current audience towards content consumption on television. The analysis of gathered data concludes Bollywood as the prominent content generated domain for television in India. Taking this finding as the base, in the later section, this paper proposed protocols for using this everlasting Bollywood impact to cater the challenges of maintaining social connect via emerging technologies of Smart TV applications (apps).

Keywords Indian television · Smart TV · Bollywood

1 Introduction

The spread of popularity, appeal and acceptance of television into family life is unparalleled in human history. Over the past few decades in the developing world, the growth of television has been extraordinary. Since 1980s in Asia, the number of television sets has increased more than sixfold, from 100 to 650 million [1]. In its

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early era, television watching was considered as the greatest single use of "free time" in both post-industrial societies such as the U.S. as well as in industrial and many preindustrial societies [2]. The children by the age of 4 used to spend an average of 4 h a day viewing television and youth devoted more time watching television than any other activity except sleeping [3]. Lots of studies have demonstrated that the content and exposure provided by television can influence the attitudes and behavior of its audience. Gentzkow and Shapiro [4] find that television viewership in the Muslim world affects attitudes toward the West. In the developing world, Olken [5] shows that television decreases participation in social organizations in Indonesia.

Since its introduction in 1959, television in India is seen as a means to educate, inform and create a feeling of national identity and help maintain national unity. This leads to government's priority in expanding the reach of television. India currently has over 277 million individuals with television sets, of which over 145 million have access to Cable TV or Satellite TV [6]. In the nineties, the expansion of television has taken a giant leap from less than 4 million to over almost 60 million television in Indian households. It also covers the remote rural communities which even lack schools, medical facilities and other basis amenities. Television as means of communication no longer distinguishes between the remote rural and the privileged urban population. Thus, it becomes one of the primary medium for creating a social connect among the diverse population.

2 Aim of the Study

Television, being a family medium in India, is watched by the entire family. In a typical viewing situation, family members from 4 to 84 years and friends and neighbours view television together. For the first three decades, the content was primarily focused toward news or information about economic development since almost all broadcasting was in the hands of the state [7]. The liberalisation of broadcasting industry in 1991 leads to the introduction of private foreign satellite television. The private satellite television began to emerge in the absence of any media policy. Along with the official network, Doordarshan, Indian households started watching cable television. While none of the private foreign television channels telecast anything related to Indian context, this fueled the launch of channels like Zee TV, India's first private Hindi-language and most successful satellite channel. The Zee network has aimed to reach the mass market by pioneering movie-based television entertainment including Hindi film and film-based serials, music countdowns and quiz contests [8]. It is followed by other private satellite channels like Sony, Asianet, etc. They generated more Indian context based content like religious programmes, mythological epics, fortune-telling, etc. It leads to the better acceptance of these channels among the Indian television audience compared to the already established private foreign channels. This scenario implies that along with television being a powerful medium, its potential can be exploited only if the socially acceptable content is served through it.

Along with the increase in reach of broadcasting services, the television itself keeps evolving. The amount of data coming into the eyes, ears, and brain while we watch television has been constantly escalating. The new generation of television set with features like HD display is no longer a box in the corner. Now it is dominating family life with its visual and aural presence. And in the coming years this will only bring further advances. The rise of internet has enabled new forms of social interaction and connectivity. The advent of digital television allowed innovations like smart TV which is an example of technological convergence between computers and televisions. Besides the traditional functions of broadcasting media, it can provide services like on-demand media, over-the-top content, etc. Majority of these services are provided through the software applications or apps available through TV app stores. This technological advancement has opened a new space in television domain which demands an intervention to cater the expectations of TV audience.

Therefore, in this paper initially we studied the current scenario of popular television content and the mental model of the existing television audience through their current viewing pattern. This data is analyzed in an attempt to bring out the domain which is contributing to the major chunk of that content generation for the audience. Taking those insights as the base, the proposed protocols are drafted for Smart TV app content which could increase its probability of acceptance and making it as another effective service delivered through this everlasting medium for social connect called television.

3 Varied Facets of Indian Television Content

With the mutual effect of broadcasting liberalization and technological advancement of television, the amount and variety of content served through various television channels increased exponentially. In order to emerge a pattern out of it, the following user study is conducted. This involved the research methodologies like market segmentation, surveys, interviews, affinity mapping and card sorting.

3.1 Target Users

As depicted by the literature provide in the previous sections that television has its reach to almost every section of the society. So, the Indian population as target user is segmented into different user sets. The existing approach of market segmentation which involves dividing a broad target market into subsets is used for this purpose. The two most common forms of market segmentation i.e., Geographic segmentation and Demographic segmentation are benchmarked to classify the user sets in our context. The five different user sets which emerge out of it are defined based on the parameters namely location, age, profession, economic status and gender. The study is conducted on 10 users in each user set. Thus, providing a collective data of total 50 target users. For each set, the primary parameter is consciously varied while other parameters are kept random. For e.g., the user set with age as the primary parameter contains one user each from the range of 0–10, 10–20, 20–30, …, 90–100 years. Thus, making a set of total 10 users spread across the broad range of age. Similarly, the other user sets are created by picking the 10 users in each to cover the broad range of its primary parameter.

3.2 Questionnaire and Data Collection

A common questionnaire for all the five user sets is created. It covers questions related to amount of time spent on television, most viewed channel, favorite programmes, etc. This questionnaire is exposed to the users for data collection through two different techniques. First one is direct one-on-one interview which is used for the users who are available in close proximity and don't feel comfortable with accessing computer. The second one is online survey to gather data from remote users.

3.3 Analyzing Patterns

The data collected through the questionnaire provided a diverse content. The concise content is driven out of it primarily using two different user research methodologies namely affinity mapping and card sorting. Both affinity mapping and cord sorting methods emphasize on grouping the bulk data to form logical clusters out of it. These clusters are not created based on the categories of television channels like news, entertainment, music, etc. Instead they are created based on different domains which contributes to the content generation for television. This approach is taken because the aim of this study is to investigate the primary source of content and not the type of content itself. The five different domains which emerges out as the clusters with maximum elements are namely politics, Bollywood, cricket, religion and domestic relations.

3.4 Results and Conclusions

All five different domains are ranked and mapped against each of the five user sets. The highest ranked domain in a particular user set is assigned the maximum of 5 points while the lowest ranked domain is assigned minimum of 1 point (Fig. 1).

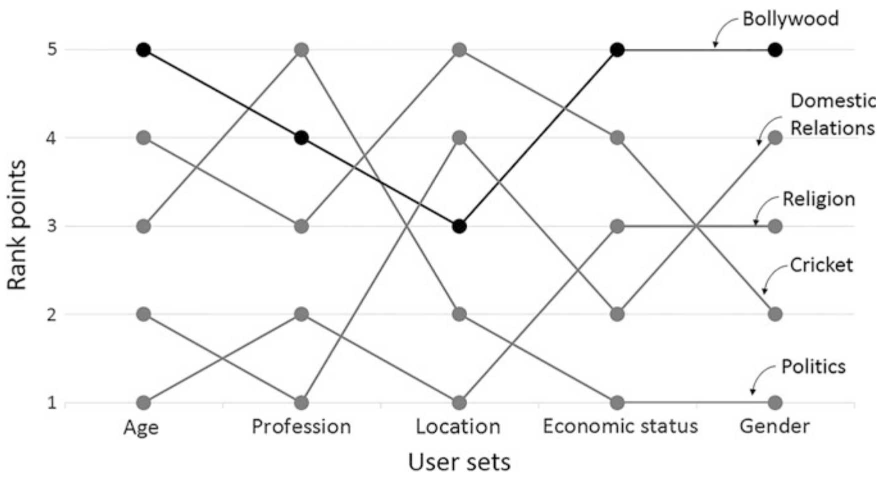


Fig. 1 Comparative ranking of each domain w.r.t. the defined user sets

The comparative analysis depicts that Bollywood as the domain holds the highest average rank all across the different user sets. This result concludes that Bollywood as a domain produces the most acceptable content throughout the wide range of Indian television audience. Thus, becomes a backbone for creating an effective social connect with the existing audience in Indian context.

4 Feasibility of Bollywood Content for TV Apps

As depicted from the outcome of user study conducted in the previous sections, Bollywood as a domain holds the key for generating the most acceptable content among the diverse television audience of Indian population. In the scope of this paper, we are targeting to cater the need for binding the same audience with the emerging new service of TV apps taking Bollywood domain as the base for the same. This TV app service can be distinguished from the prevailing broadcasting service in various aspects. Therefore, prior to the appropriation of Bollywood content for TV apps, the following feasibility analysis is performed.

4.1 Categorization of Bollywood Content

Among the broadcasted services, Bollywood serves as the source for variety of content. Through the collected data and the level of interconnect between the content and Bollywood, it can be segregated into three different categories primary, secondary and tertiary.

Primary category belongs to the set of television content which takes the Bollywood generated data unaltered and showcase it on the television screen. The movie and music TV channels majorly focus on this category of content. Secondary category serves as the extension of primary category content. The programmes under this category evolve their content out of the content delivered from Bollywood instead of taking it as it is. Thus, creating a secondary level dependency. Few examples are celebrity news shows, dance shows, singing shows, etc. Tertiary category looks toward Bollywood for the inspiration to generate new content with additional elements. Cartoon shows and spoofs are some of the well accepted content from this category which merges the Bollywood inspired content with the element of humor.

4.2 Feasibility Analysis for Smart TV Apps

Each category of the Bollywood content is analyzed for its feasibility in the context of Smart TV apps. Since the TV app store is still in the nascent stage, the android mobile app store is taken as the benchmark for the feasibility of converting each category's content effectively into app services. Each of the three content category is mapped to the related apps among the top 500 in the android mobile app store (Fig. 2).

Even though mobile phones are not primarily used for Bollywood content consumption, Bollywood content based mobile apps share nearly 5% of the top 500 apps in android store which is a significant figure. All three types of content contributes to this figure thus verifying the feasibility of each to be transformed into app based services. The primary Bollywood content in the android mobile store is delivered mainly through on-demand movie and music libraries. The secondary

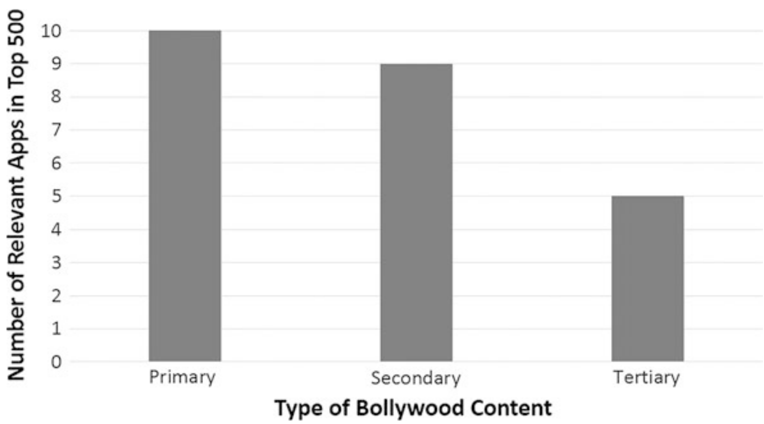


Fig. 2 Benchmarking the numbers of relevant android apps

content is consumed through the apps like news and karaoke. The movie based game apps majorly contributes to the tertiary Bollywood content in the mobile app store.

5 Formulation of Protocol

Following are the set of protocols for Smart TV apps which are presented for effectively leveraging the already existing grasp of Bollywood among the Indian television audience. These protocols are targeted to serve as the basic guidelines for making Bollywood based Smart TV apps. Some of them could be generalized and are relevant for other television content domain as well but here we are discussing them from Bollywood domain point of view only.

5.1 Point of Intervention

In the current scenario, mobile apps have already evolved to the extent that their consumption is at the same level to the primary service of a mobile phone i.e., making calls. But remember that the primary use of the television is still to consume the broadcasted content. TV apps in their early periods are only going to be considered as an add-on to the primary broadcasting services. So, the existing experience of consuming broadcasted content should be the trigger point for motivating the user for launching any particular TV app service. For the Bollywood content, especially of primary category, the viewing experience is more immersive in nature i.e., the audience prefer to consume it uninterruptedly in a single long stretch of time period. Therefore, this trigger point shouldn't hinder the existing level of viewing experience for any of the content category by large extent.

5.2 Category and Format Correlation

Based on their layout, the TV apps are divided into three type—Full-screen, Single-Wide, and Ticker apps [9]. As the name suggests, each of them captures different amount of screen space thus providing different viewing experience to the audience (Fig. 3).

The primary, secondary and tertiary Bollywood content engages the viewer into different level of immersive experience. Therefore, the degree of their suitability varies with different display types of Smart TV apps (Fig. 4).

Full screen apps are not suitable for primary content type since it leads to an interrupt in the long term viewing experience of primary broadcasted content. While tertiary content type requires user to experience a whole new content apart

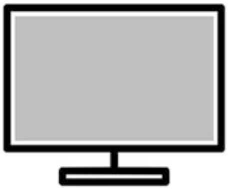
Display type	Description	Screen layout
Full-screen application	Fills the entire screen with an application.	
Single-wide application	Makes an application displayed only on a part of the screen.	
Ticker	Keeps an application on the TV screen while you do other things with your TV.	

Fig. 3 Smart TV app display types and layouts by Samsung

Smart TV app format / Bollywood content category	Ticker	Partial	Full screen
Primary	Strong Positive	Medium Positive	Strong Negative
Secondary	Medium Positive	Strong Positive	Medium Positive
Tertiary	Medium Negative	Medium Positive	Strong Positive

Fig. 4 Correlation matrix between Bollywood content categories and Smart TV app formats

from the broadcasted content. Thus, full screen TV app format is more apt for this scenario. Similarly, the suitability between other format and content type based on viewing experience is distributed among four level—Strongly Positive, Medium Positive, Medium Negative and Strongly Negative.

5.3 Extended Personalized Experience

So far television is always considered as the one way interaction medium. Also, it is looked as a family device and not a personal device. But, the upcoming Smart TVs are evolving it into a responsive two way interaction medium. They are now coming with the features like personalized logins, recommendations, search etc. As evident already, Bollywood as the domain has the huge scope of producing diverse content for television. Also, the television audience is always in the lookout for more and more of Bollywood based content. This flexibility should be exploited through the new Smart TV features to extend the Bollywood flavor by adding the personalized experience for the viewer. 'Personalization' is the capability to adjust the content being provided, based on an understanding of that user and their context of use [10]. For example, the Smart TV apps based on personalized features like recommendation service can reduce the cognitive overload of deciding what to watch next and results in the better acceptability of the app as the service. The content relevance is the key here. The more a viewer finds the app content relevance, the more is the chances of app's acceptability.

6 Conclusion

This paper has shown one of the way to make a smooth transition from traditional television to the newly emerging smart TV for the Indian audience. This approach proposes that instead of directly exposing the user with new technology and content, it is better to exploit the existing mental model of the audience and use it as the base to build content for new technology. Thus, avoiding the unnecessary need for creating the new user base for new content. In this exploration, Bollywood is an element which is inseparable from Indian television and therefore should be utilized efficiently for strategizing any protocols in the television domain for Indian audience. Under the scope of this research paper, we have focused only on primary level of content segregation. Thus, the data clusters like Bollywood, politics, etc. are made from a broader perspective. Considering that this paper is just the first step in identifying the significant cluster of content, similar studies as future scope are necessary for further classification on secondary level of the dominant cluster i.e., Bollywood, in order to retrieve more focused content within that cluster.

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Semiotic Analysis of Digital Medium of Education

Priyanka Bharti and Jivtesh Singh Aulakh

Abstract Digital based learning is majorly contributing in imparting quality education in world. An Indian government is also trying its best in upgrading our nation educational system by e-based learning such as games, apps, websites etc. E-learning requires visualization and imaginative power of the user (kids), in order to understand the real application of the digital medium w.r.t. nature. So, an attempt is made to understand the process by which kids (of elementary school) interact with the digital media to understand the real time surroundings in nature. Moreover, in the study, what type of elements in digital medium becomes relevant and irrelevant during the time of delivering the goal; effective comprehension.

Keywords Educational gaming application · E-learning · Elementary school · Nature · Quality education

1 Introduction

There is a genuine concern for elementary level education in every country as it is considered to be the most crucial stage of compulsory education for a child, where he/she is primarily exposed to the society to foster his/her thinking ability that will later aid in decision making capabilities. So, rationally the prime objective of the curricula should be to improve a child's cognitive, emotional, physical, sensory, reflective, visual imagination, communication and social developments. New millennial learners are flourishing in between digital media and technology due to which traditional ways of communicating knowledge is falling weak to deliver meaningful learning. New technology (e.g., mobile technologies, open content, learning analytics and educational games) is competent of bringing in real time

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problems and experience within the classroom space which endorses student's interest for learning, with content and components that helps in constructing an environment (combination of visuals), the relationship between the components, ideologies and the connotations of visuals, that include a process of forming a common consensus [1]. Collaboration of technology with education sector has brought in a revolution in an effective comprehension which includes analysis, contents and component relationship with visuals and building ideologies. As a result, many new methods of teaching have evolved such as activity based learning (ABL), multi grade multi-level (MGML) etc. which has a vigorous impact in the education sector, because it facilitates playful learning environment (PLE) [2]. It is an innovative, technology—enriched play and learning environment whose components are located indoors as well as outdoors [of the classroom]. Learning in such an environment takes the form of content creation and engagement in physical gaming and play [3]. There are 46% of elementary school student who feel cynical towards school and it has been proved that innovative socio digital participation encourage them to learn and generate positive emotions [4]. Groups of children can learn to use computers and the Internet on their own, irrespective of who or where they are [5]. According to a study 54% of 21st century kids start using mobile devices when they are 5–8 years old, 30% of the apps on parents' mobile are downloaded specially for their children's usage and 77% of the parents accept that usage of tablet increases children's learning and creativity [6].

2 Literature Review

Learning means the act of acquiring knowledge or skill and it is considered to be more efficient if it is done in a playful way [7]. According to Marc Prensky's, different learning outcomes are best learning through particular types of learning activities. He says that we all learn (a) behaviors through limitation, feedback and practice (b) creatively through playing (c) facts through association, drill, memory and questions (d) language through imitation, practice and impression (e) reasoning through puzzles, problems and examples [8] and learning through electronic medium is known as E-learning. It refers to the appropriate use of ICT (information and communications technology—or technologies) to enhance the learning—and can thus take place on school or in any other context [9]. There are basically two types of e-learning: synchronous and asynchronous [10]. Synchronous, means "at the same time," involves interaction of participants with an instructor via the web in real time. Asynchronous, means "not at the same time," allows the participant to complete the Web Based Training (WBT) at his own pace, without live interaction with the instructor. There is another form of learning called 'blended learning' is emerging gradually which refers to a mix of e-learning with traditional teaching and learning practices. Typically, there is a combination of face-to-face interaction with online learning to ensure maximum effectiveness (works more effectively during higher education level).

E-learning is a device dependent learning (device plays a medium of interaction). Technology delivers a flexible tool to a child where they can learn in the way they are comfortable with. They enjoy the affordance of replaying the activity to numerous times, till they are satisfied or understood it well. The power and the approach of learning style lies in the hands of a child, which endorses their curiosity of learning. This is a significant development because it challenges the view that new ideas and innovation flow from privileged centers of creativity which reinforce existing hegemonies of power relations [11]. Used well, technology can make a unique and substantial contribution to the education of young children [12]. E-learning has significant and positive affect on various literacy skills and knowledge (including specific print concepts), story retelling, reading books, listening, predicting and sequencing. Besides curiosity and peer interaction, it is children's desire to learn which drives them to explore the environment in order to satisfy their inquisitiveness. And when children explore their environment, they gain new experiences which they relate with their previous ones and thereby, it leads to new learning [13]. Pedagogic methods like Minimally Invasive Education (MIE) involves none or minimal intervention from a teacher and uses learning environment to generate an adequate level of motivation to induce learning in groups of children [14]. These developments are responsible for the paradigm shift in the context of education and research. It generates the need for new curricula and pedagogical process [15].

3 Research Question

Apart from advancement in education sector and technology, there are few things which still goes missing from a child's learning phase; connection with nature which magically triggers learning by action/doing/listening etc. The reasons can be many such as chunk of physical space, new life style, living standards etc. due to which even basic information is required to be conveyed through books or stories (if parents are aware/interested to mention), e.g. lizards go for hibernation, cow gives us milk, cockroaches produce hissing noise etc. so why not represent nature and natural phenomena by the help of technology with real time experience.

Learning and comprehending task/thing is a phenomenon of creating perception and memory in our cognition, which is meant to be efficient if it can be recalled/retrieved later successfully. A platform that can rewind the lost connection of nature with child by replicating nature and its phenomena without amalgamating it with artificial task that can facilitate learning by action (learning naturally), applying all five senses of the body.

4 Overview

E-learning in India is still young but slowing thriving in the market after 2013 because of the growth of the internet management [9]. Market is flooded with immense games, apps, websites and videos that contribute in imparting knowledge in a playful manner for the child undergoing his/her elementary level of schooling [16]. Most of the apps/games task are based/inspired from their curricula syllabus which is like converting class task into digital task in order to provide better understanding among students in a conscious way. Learning is more efficient if it is done unconsciously; playful environment is one of the ways to achieve it [16, 17]. Hence, an approach has been taken that do not give emphasis only on the school task or only solving any problem but on recognition, problem understanding and then solving issues related to problems. Recognition is a first step of comprehension after a sight/touch/hear/taste/smell. There are few apps in market that is based on recognition but not dedicated for the kids in order to teach them.

5 Methodology

Primary data was collected using questionnaires from students (30), parents (30) and teachers (30) in schools across the states of U.P., Bihar, Jharkhand and Punjab. Secondary data was also collected and studied using online questionnaires, web portals and app stores that are further followed by focused group discussion. We followed UXD process to develop wireframes, prototype testing (using Axure prototyping tool), make iterations, then incorporating Visual Design assets to design the final product.

6 Findings

All the data were analyzed (questionnaires and focus group interviews transcript) and following meaningful insights were generated out of it:

i. All the teachers are not equally trained for teaching, which affects the efficiency of the teacher's way of imparting knowledge to the children.
ii. Classroom studies are not always effective in the case of millennium learners as it turns into a monotonous activity due to which learning becomes a forceful activity for them. Too much of technology and no playgrounds in schools and societies do not promote a good environment for learning. As a result, there is a big disconnect between child and nature.
iii. Technology offers an immense flexibility w.r.t. usage but it has been highly used in the field of entertainment and least for the education sector. Therefore,

a lot more can be extracted out of this facility in order to facilitate meaningful learning to the new millennial learners.

iv. Learning while playing is one of the best ways to do it. But it need to be planned as its not direct method of teaching but indirect form of imparting knowledge.

7 Proposed Solution

With the present world becoming more and more connected with increase in technology, we, humans are becoming more and more disconnected from the nature—the greatest teacher. The great scientist Albert Einstein said, “We still do not know one thousandth of one percent of what nature has revealed to us”. And, this disconnects of nature and children (elementary students) will be a big deal, as they will learn less from ‘the greatest teacher’. It is very common to see now-a-days that kids are emotionally attached with the virtual playing tools like games, app, videos on mobiles and tablets which serve as. Another reason for disconnect is reduction in number of playgrounds. With the current rate of deforestation and population explosion, there has been a reduction in area of playground/open space for children. This completely disrupts the connection between the nature and a child (elementary student). Playing in the playground not only makes children aware of biodiversity, trees, plants, insects, but also helped in development of EQ (Emotional Quotient), BQ (Body Quotient) and MQ (Moral Quotient). Einstein also stated, “Look deep into nature and then only you will understand things better”. We tried capturing all the elements in the game with the help of visual type because it may take over the years might help in convincing government to make more playgrounds and parks available for kids to play. But to nail down, an immediate solution, to make students aware about nature and sync up with it and learn from it was of prime importance. Hence, our solution aimed at a disruptive idea of using technology and visual component to make students pay attention to nature and start observing it and learn from it.

Another hurdle which is not in direct control is the quality of pedagogical process elementary at level. Due to increasing strength of students per class per teacher, it is becoming difficult for teachers to provide proper attention to each student. Moreover, quality of education of teachers differs from individual to individual. Current education system is focused on how to earn a living (based on an IQ grade system), making it a mechanical business oriented process. Again, our solution was to facilitate knowledge/information efficiently related to curriculum and help aid teachers.

Each and every game on the portal/platform will be based on story line so that a student/child can comprehend it easily without any extra cognitive load of memorizing the instructions with an appropriate visual component. The visual components used in the proposed solution are:

i. Composition—Day to day surrounding (Level 1: Drawing room, Level 2: Garden, Level 3: Pond/water body near the garden/house) of a kid is used for different levels. These surrounding were chosen in order to keep user (child) imagination realistic as they can access these surrounding in their daily (almost) life. Hence, the purpose to connect a child with nature will be catered easily, because after playing/interacting with the game/app he/she need not to imagine a surrounding to connect the task performed by them on the device. He/she can just step out and start performing the task in real world (insight from testing phase).
ii. Visual Language—The visual language is similar to their course book's visual because of the fact that we want to build a relationship between the child's book and app. This app is not targeting to bring disconnect between the tangible (book) world and virtual (technology/device) world. The main aim is to cater learning even from surrounding including books.
iii. Semiotic signs—Visual sign: Objects present in the particular level dedicatedly describes the particular surrounding (familiar with child with less imagination as all objects may or may not be arranged in the similar manner in his/her house). Iconic signs: Objects in the particular surroundings and the insects/animals hidden behind/on it.

7.1 Story of the Game

One among the proposed story game: A boy has a nightmare related to his homework of locating the habitat of various insects, birds and animals. The boy sleep walks and enters the living room, first stage. The player needs to help the boy find the insects, birds and animals. The uniqueness of the game lies in its naturalism. Usually, we hear noises of insects, birds and animals in nature and from the noise when we try to locate its source; and find the insects, birds and animals. E.g. A shrill creaking sound produced by crickets called 'Chirping' sound. Similarly, these creatures are hidden behind the various objects/things and mainly the noises they produce are available. So, the player needs to carefully browse through one object to another and hear the noises. The intensity of noise of the creature hidden behind the object will increase and that of others will decrease. Upon selection of an object/thing, player will be given the list of creatures and the player needs to select the correct option of the creature who was producing that noise hiding behind the selected object/thing (its habitat). This game is time based. A player needs to find (the habitat) all the hidden creatures in limited given time. Upon giving a correct answer, player is awarded with a clapping sound; otherwise, player is penalized with a reduction of 5 s in the timer. When a player gives all right answers, he/she moves to the next level. The second level is in the park outside the house, where amount of given time is reduced to increase the difficulty. Once second level is completed, player needs to help the boy in the third stage which is the adjoining

Fig. 1 Splash screen

pond next to the park, where in again difficulty is increased by reducing the total time to find the creatures (Figs. 1, 2, 3 and 4).

Youtube link: https://www.youtube.com/watch?v=cCH-SR9bJ-4.

The takeaways from the proposed educational game are as following:

1. Direct involvement of the player as the student shown in the game.
2. Making students aware about the habitat of various insects, birds and animals.
3. Making students aware of the sounds produced by various creatures.

Fig. 2 Level one—living room

Fig. 3 Level two—park/garden

Fig. 4 Level three—pond

4. Enhancing auditory ability in recognition.
5. Natural way of finding the creatures that is locating the source of noise.
6. Indirect form of learning.
7. Students may start observing the same in real life in nature.
8. Students may not only know the creatures and their habitats but will also know the sound/noise they produce.

8 Conclusion

E-Learning is an upcoming future of the education sector which is continuously getting complimented with new approaching technologies. Proposed solution is an attempt to build a relationship between nature and kids, by virtue of technology. The main aim is to develop/support another perspective of learning i.e. with nature. It is not mandatory that learning can only happen only in the condition when an executor is present, it may also take place in absence of it. We are trying to introduce nature through a technological medium to a child as an executor of knowledge because of disconnect between the nature and child with semantic information.

9 Future Aspects

In future, we will try incorporating VR device and/or augmented reality technology so that students can get real time experience and have more enriching learning.

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Domestic and Global Designs in Hair Care: A Study of Aesthetic Preferences of Indian Users

Toney Sebastian, Pradeep Yammiyavar and Stevan Jones

Abstract A study of domestic and global hair care package graphics was conducted for understanding aesthetic preferences of Indian users. Package graphics of products from domestic and global markets were selected using purposive sampling. The study employed a quantitative Image test, which revealed that the users preferred graphic designs of global brands over domestic brands. User evaluations using Eye Movement Recorder and qualitative interviews were conducted to understand specific elements of the aesthetic preferences, which indicated that presence of logo or ingredient visual with high clarity, and highlighting cap with gold bands or with colours of logo/ingredients have high influence on aesthetic appeal. An improved version of the least accepted design was developed by incorporating the findings and relative user acceptance was assessed. The study revealed that over 80% of users among a base size of 49 preferred the improved design over the original design for 'beautiful' and 'premium' attributes.

Keywords User perceptions · Indian users · Package graphics · Aesthetics

1 Introduction

Since independence, Indian economy was following socialistic and self dependent policies, which resulted in growth of domestic brands particularly in consumer goods segment [1]. However, in early nineties, Indian government took steps to ease restrictions on imported goods [2], resulted in flurry global brands entering

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India, while numerous products are still produced domestically [3]. This created a choice overflow for Indian users [4]. Last decade saw instance completion between domestic and global brands in India, and in some categories global brands overtook domestic brands [5]. Increase in disposable income, westernization of the culture, and changing lifestyle of the users were some of the catalysts for these changes. Indian users were also become more brand-conscious and are spending more on branded products. Researchers also commented that users in developing countries are perceiving usage of global brands, particularly brands from the United States (US) as a means to gain prestige in the society [4, 6]; all of these are helping growth of global brands.

Indian user's perception towards global brands has attracted considerable amount of academic research, particularly assessing perceptions based on brand names and brand images [7, 8]. Kinra [7] investigated Indian consumer's attitudes towards local and foreign brand names and found that foreign brands have a perception of higher on technology, quality, status and esteem than Indian brands. Bhardwaj et al. [8], did a study of US and Indian apparel brands among Indian users, and demonstrated that users have higher quality perception, and better awareness and loyalty for US brand (Levis), compared to domestic Indian brands. Despite the abundance of studies on user perceptions of global and domestic brands, researches in the area of aesthetic preferences of global and domestic brand designs are scarce.

Within brand design, package graphic design has significant importance, especially in consumer goods category. Several researchers have advocated usage of packaging as biggest medium of communication, because of its wide reach to purchasers of the category [9–11]. Over the past several years, researchers have addressed several aspects of package and package graphic design [12–18]. According to Vyas [12], and Silayoi and Speece [13] design elements of package, have great influence on users choice of the product. Investigation of buying behaviors of female consumers in cosmetic category by Riaz et al. [15], revealed that attractive packaging designs have strong influence on buying. Khan and Khan's [16] study of female skincare users in Indore (India) showed that products with attractive packages have a perception of higher quality. Considering the amount researches in user perceptions of domestic and global brands, and in package graphic designs, any research in the area of comparing package graphic designs of global and domestic brands would be attractive for academicians as well as brand designers.

A study of hair care package graphics was conducted among young Indian users to understand aesthetic preferences of domestic and global brand designs. Hair care was chosen as the category for research as it is a fast growing category in India, with 14% value growth in 2014 [5]. Additionally, hair care market in India is lead by global companies. Hindustan Unilever Ltd. with global brands such as Dove, Sunsilk, Clear, Clinic Plus and Brylcreem, and Procter & Gamble with global brands Pantene and Head & Shoulders are the market leaders. These brands are available across all retail channels in India [5]. The study revealed that users prefer graphic designs of global brands over domestic brands in terms of aesthetic appeal.

Study also provided insights on specific design elements with high influence on aesthetic appeal for Indian users.

2 Research Methodology

Our study employed an Image test using quantitative and qualitative techniques for understanding user preferences and identifying design element with high influence on user preference. Package graphics used for the study were selected using purposive sampling technique. Eleven students of Indian Institute of Technology (IIT) Guwahati, who are natives of different parts of India, participated in the study. The quantitative Image test was used to numerically measure user preferences, while qualitative technique was used for identifying specific design elements that influenced user preferences. The findings were further verified using an Eye Movement Recorder based user evaluation. An improved version of the least accepted graphic design was then developed with the help of a professional designer by incorporating the findings. The relative acceptance of the new design compared to the original design was evaluated using an online survey among 49 Indian users, recruited using social media.

2.1 Image Test

Image tests using traditional qualitative and quantitative researches are widely used in package design research [11]. Qualitative and quantitative studies help to identify user preferences and the factors that drive user liking. Companies use the insights from qualitative and quantitative researches for optimizing the designs to enhance user acceptance [19].

Quantitative research using scaling is a general approach for concept testing as well as Image testing [20–23]. Carr et al. [21] used a nine point category scale to assess how consumers match concept statement with products. Moskowitz [23] used a scale ranging from 0 to 100 for investigating the relationship between sensory, liking and image attributes of soaps. Our study employed a five point scale balanced at three, for measuring aesthetic preferences of the images.

Qualitative research involves systematic collection, organization, and interpretation of textual data derived from a conversation or observation. The analysis can be used in the exploration of meanings of social phenomena experienced users in their natural context [24, 25]. Qualitative techniques are very widely used in modern day market research. Qualitative research is highly efficient when the researcher's goal is to acquire user's everyday knowledge [26]. Qualitative research is relevant for our research as the objective is to understand specific elements of user acceptance, which is within the limit of everyday knowledge.

2.2 Eye Movement Recorder

Eye tracking studies are based on tracking the movement of the pupil as it moves across an image [27]. Eye tracking is highly effective at measuring the way users navigate a design, i.e., what they look at first, what pause longer, and what they go back to and study again. One drawback of EMR based study is, it evaluates the design isolation and the total context final execution is not considered. For example, elements such as promotions, advertising, etc.… are not considered when evaluating design using eye tracking. This limitation is not relevant for current study as scope of current study is limited to aesthetic appealing, and not to purchase decisions.

2.3 Sampling

A purposive sampling technique was used for this study. A purposive sample is one in which the researcher uses personal judgment to determine if certain items of a population best serve the purpose of the study [28]. Purposive sampling is relevant for this study as no prior research is available to the best of knowledge, in the area of hair package graphics among Indian consumers.

2.4 Materials

Package graphics used for the study where collected from Amazon website [29], using an internet enabled computer. A total of eight domestic and global hair care products, from six different brands (Pantene, Dove, Herbal Essence, Patanjali, Indulekha and Ayush) were selected. For global brands Pantene and Dove, graphics of products marketed in India as well as in US were collected, while for Herbal Essence, only one version was available. To avoid variability and user bias due to difference in product types and package color, shampoo products with 'white' as primary package color was chosen for the study (Fig. 1).

A questioner was developed for quantitative and qualitative user evaluations. For quantitative evaluations, a five point balanced scale was used (5 for strongly agree, 4 for agree, 3 neither agree nor disagree, 2 for disagree, and 1 for strongly disagree). Consumers were asked rate individual package graphics, against 18 keywords. Keywords tested included beautiful, premium, bad, boring, ordinary etc.

Qualitative evaluations were done by showing package graphics in groups, as one group of all eight visuals together, two groups of three visuals (domestic brands together and USA brands together), and two groups of two visuals (Indian and USA

Fig. 1 Package graphics used for the research. From *left*, Dove USA, Pantene USA, Herbal Essence, Ayush, Indulekha, Patanjali, Dove India, and Pantene India (*Source* www.amazon.com [29])

Fig. 2 Eye Movement Recorder based study conducted at UE Lab, Dept. of Design, IIT Guwahati (Sept 24–26th, 2015)

Pantene and Indian and USA Dove). Graphics were shown in groups as the objective for qualitative evaluation was to get insights on specific drivers of user acceptance, by comparing across the visuals. Questions included, which graphics is attractive, why do you think it is attractive, which is not attractive, why it is not attractive, which one looks most 'premium' etc. (Fig. 2).

Further, an Eye Movement Recorder based user evaluation using Tobii eye movement recorder at UE Lab, IIT Guwahait was conducted for verifying the findings. Package graphics were shown the same way as it was shown for qualitative and quantitative studies. For validation, an improved version of one the least accepted graphic design was developed by incorporating the findings, with the help of a professional designer. The relative acceptance of the improved design compared to the original design was evaluated using an online survey among 49 Indian users, recruited using social media from 21st August to 23 August 2016.

3 Results and Observations

Results and observations are grouped into Image test and Eye Movement Recorder based observations.

3.1 Image Test

Quantitative image test provided insights on aesthetic preferences of the users. Users identified package graphics of global brands such as Pantene, and Dove as more premium, beautiful and trusted than domestic Indian brands. Among domestic Indian brands, Package graphics of Ayush received highest score (neutral) for premiumness, and beautiful keywords. From the qualitative depth interviews, it was revealed that users given higher score for Ayush because of usage of gold in the graphics. Among global brands, Herbal Essence received lowest score (neutral) for premiumness and beautiful keywords, which users described as because of cluttering of the graphics and poor clarity of the ingredient image used on packs. For negative aesthetic keywords such as bad, boring and ordinary, package graphics of domestic brands received higher score compared to global brands.

When used highly negative keywords like ugly, and hate, users rated neutral or negative (disagree/strongly disagree) for all designs. From qualitative interviews, overall simplicity (not too many contents) of the design, use of a logo, and use of gold and/or glossy blue colors were identified as primary reasons for better aesthetic appeal of global brand. Results from quantitative user evaluation are presented in Figs. 3, 4 and 5.

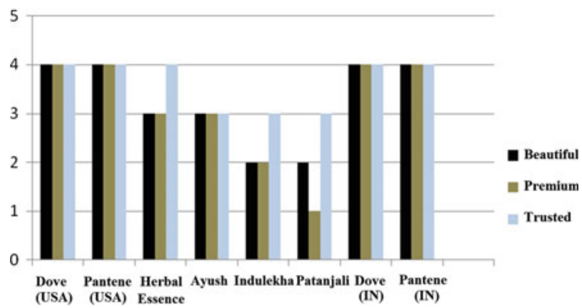

Fig. 3 Chart representing median score of user rating on a scale of one to five for keywords beautiful, premium and trusted (N = 11). Scale 5 represents Strongly Agree, 4 for Agree, 3 for Neutral, 2 for Disagree and 1 for Strongly Disagree

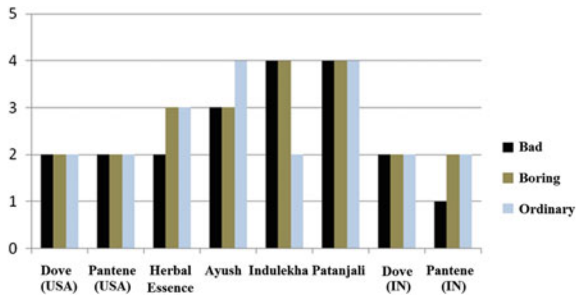

Fig. 4 Chart representing median score of user rating for keywords bad, boring and ordinary. Scale 5 represents Strongly Agree, 4 for Agree, 3 for Neutral, 2 for Disagree and 1 for Strongly Disagree

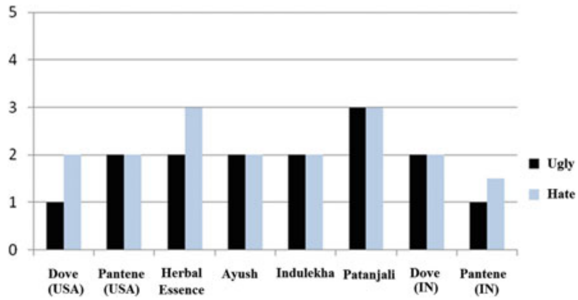

Fig. 5 Chart representing median score of user rating on a scale of one to five for keywords Ugly and Hate (N = 11). Scale 5 represents Strongly Agree, 4 for Agree, 3 for Neutral, 2 for Disagree and 1 for Strongly Disagree

3.2 Eye Movement Recorder

Eye movement recorder data analysis gave insights on user's viewing pattern. When all the eight graphics were shown together, most of the attention was focused on the upper half of the bottle, particularly on brand name, logo, and ingredient visuals. EMR also helped validate the findings such as presence of gold bands, and highlighting cap as whole or cap opening area with colors of logo or colors of the ingredient visual have high impact on user's aesthetic preference. Examples of hotspot and viewing pattern analysis from EMR study are presented in Figs. 6 and 7.

3.3 Design Modification and Surveying

An improved version of one the least accepted graphic design was developed by incorporating the findings, with the help of a professional designer. The design was

Fig. 6 An example of hot spot analysis from EMR study, recorded by showing all package images together

Fig. 7 An example of individual package viewing pattern from EMR study (recorded by showing one package at a time)

modified by changing the cap opening area to golden colour, adding gold band on the cap, changing the ingredient visual, reducing the cluttering by removing less important texts, and improving overall clarity of colour. The overall shape and brand name were kept unchanged. The design elements used for developing improved design is shown in Fig. 8.

An online survey was conducted among 49 users to assess the relative acceptance of the improved design compared to the original design. The designs were presented side by side and participants were asked to select one image that best fits for each of the keywords given. Keywords included 'beautiful', premium, 'trusted' etc. The results of the survey are presented in Fig. 9. It can be seen that over 80% users selected improved design for 'beautiful' and 'premium' keywords, while for negative keywords such as 'bad', 'boring', 'ugly' and 'hate', over 80% of users

Fig. 8 Design elements like *gold color* of cap opening area, *gold band*, and ingredient visualization used for developing improved design modification

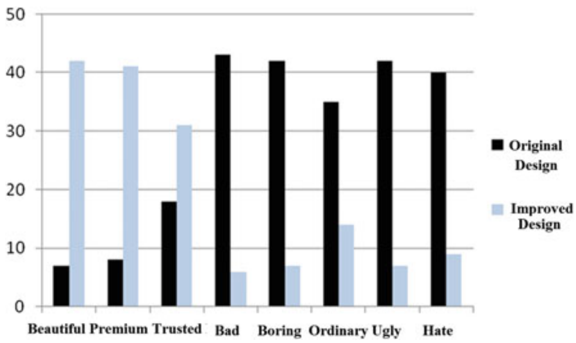

Fig. 9 Chart showing results of online survey of relative user acceptance of original design and improved design. *Y axis* represents number of users selected the design for each keyword (N = 49)

selected the original design. For the keyword 'trusted', over 60% of the users selected improved design while for 'ordinary', over 70% of users selected the original design. Based on the results, it can be concluded that the improved design has better aesthetic acceptance.

4 Discussion

The current study gives a clear indication that the users' preferred graphic designs of global brands as compared domestic brands. Although prior researches such as Kinra [7], and Bhardwaj et al. [8] studied perception of foreign brands among India users, specific elements behind better perception of foreign brands were not investigated. Results from current study suggest that design elements are playing an important role in foreign brands perception among Indian users. The study revealed that overall simplicity of the design (with less cluttering), presence of logo or ingredient visuals with higher clarity, presence of a gold band, and highlighting cap or cap opening area with colors of logo or ingredient visuals are key elements required for user's aesthetic appeal. Current research also suggests that domestic brands could significantly improve their aesthetic appeal by adapting their designs using findings from this study. Further, brands may reapply the research technique used in current study, of combining qualitative, quantitative and EMR based user evaluations in assessing user perceptions of the design. Findings from current study need to be further evaluated with graphic designs of different colored packages, and with a larger base size for more comprehensive statistical analysis. Evaluation with physical samples should also be conducted as most of the category business is still direct purchase from shops.

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Transmutative Visual Culture of Folk Festivals in a Semi-urban Scenario: A Study and Exploration of 'Magh Bihu' in Assam

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Abstract Folk festivals in India are related with agriculture and productivity. The social manners, customs, habits etc. are the principle elements with which these festivals are integrated. In Assam, Bihu serves as the most important marker of cultural assimilation that unites various indigenous groups and all such diverse constituents of Assamese community. It is a unified form of the folk songs, dances, musical instruments of the various castes, sub-castes and tribes of people, the inherent natives of Assam. As a form of performing art, folk festivals have always been an important part of culture and community life. With the onset of globalization several factors such as increasing human mobility, goods and ideas have led to the emergence of a multi-dimensional domain. In the post-industrial scenario, cities in India have become critical sites of negotiation and are expected to become some of the largest urban agglomeration of the twenty first century. This has created a pluralist identity resulting in a new multifarious culture pervading throughout the entire urban landscape. Festivals have transpired as the phenomenon of the city, and their presence in the everyday landscape weaves itself through the urban fabric dominating the popular visual culture of Indian cities. This in turn has left an imprint on the celebration of festivals like Bihu and Durga Puja providing a new dimension leading to the emergence of new vocabularies of celebration veering towards Public Design. These festivals have taken a particular installation art profile that exhibits the influences of various cultural elements. This can be broadly termed as 'festivalisation' of the city. They dominate the popular Visual Culture of Indian Cities giving a new dimension towards the study of Image making and Place making in present day

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Indian cities. This study was undertaken to explore and understand the anatomy of the newly emerged popular display of cultural elements which has given rise to new dimensions to Visual Culture in a semi-urban setting. This provides an evolution in Design thinking and Visual Culture where the vernacular practices of art and craft are brought into dialogue with the changing needs of modern cultural demands. It further leads one to analyze and observe how the artifacts associated with a folk festival reinterprets their symbolic meanings through various inter and intra cultural interactions over time. What role can the Designer play in branding these cultural phenomena while creating a unique identify of a city?

Keywords Festival · Visual culture · Culture · Design thinking · Cultural identity · Urban identity · Cultural heritage

1 Introduction

Festivals come with their colourful milieu of various cultural depictions through their celebrations. They contribute to the vibrancy of the city and give opportunity for interactions in today's busy urban life. Festivals are an integral aspect of urban spaces and urban identity. India has a rich diversity when it comes to festivals. Each festival, however, has acquired their own local colour and form through centuries of absorption, integration and acculturation. There is no fundamental difference between folk festivals and the festivals of the cultured except the difference of forms and features [1]. Those festivities in which the common folk take the initiative and give expression to their natural tendencies and capacities, their ideas and sentiments, can be counted as folk festivals [1]. Music, dance, storytelling, food, arts and crafts, form an integral part of folk festivals generally carried over from generation to generation. Festivals are an important facilitator for fostering a sense of identity of a group through the social interaction and shared experience [2]. A festival thus provides new ways of seeing these identities grounded in per formative festivals [3].

Festive spaces with their depiction of specific activity, depicting a very specific idea and representing a very specific community form vital community spaces. Various elements, in a tangle of interdependencies, are responsible for framing every kind of change that takes place in an urban environment. Isolating one from the other is irrelevant. The process of urban change is intricate, elaborate and multidimensional [4]. Studying these festive spaces within the context of urban, peri-urban/semi-urban spaces gives an interesting insight into how the visual culture of a city changes through time and context. Rahul Mehrotra, in his essay on Kinetic City [5], observes that festivals such as Diwali, Dussera, Durga Puja, Ganesh Chaturthi, etc. have transpired as the phenomenon of the city, and their presence in the everyday landscape weaves itself through the urban fabric dominating the popular visual culture of Indian cities [5].

2 Methodology

The study was conducted through data collected from field trips and literature survey done through various books, journals, articles from the web. The keywords used for searching were festivals, festive spaces, urban spaces and visual culture. By using go-along methods, participant observations, photography, and document analysis, the accommodation of various imaginaries and narratives of Magh Bihu has been studied.

3 Literature Review

3.1 Folk Festival—Magh Bihu

Bihu is a festival connected with the seasonal and agricultural cycle and is an integral part of the Assamese cultural pattern. It is one of the most important cultural markers of Assamese community. There are three kinds of Bihu celebrated at different times of the year—the Bohag or Rongali Bihu celebrated in spring, the Kati or Kongali Bihu celebrated in autumn, and the Magh or Bhogali Bihu celebrated after the harvesting season i.e. in winter. The Magh Bihu is akin to the Makar Sankranti festival observed by the people of other states of India. This harvest festival celebrated in Assam is also dedicated to the Hindu fire God, Lord Agni. On the eve of Magh Bihu, called Uruka, a special temporary temple like structure called Meji is made out of bamboo, thatch and leaves. Makeshift huts called Bhelaghar made of bamboo and haystacks are built by the men folk near the Meji to spend the night. A feast is prepared inside the Bhelaghar where the entire community participates in preparing it thus enhancing social interaction through this shared experience. The men folk then spend the night in the Bhelaghar after the feast is over. In the wee hours of the next morning, the Bhelaghar is lit in the presence of the entire community and the ashes are strewn in the surrounding fields. This is believed to bring good luck for the future harvests. Magh Bihu indicates the gathering in of the harvest. This festival fosters social interactions through community fishing, community hunting, community feasts (or communal feasts). Apart from that, various games and recreations such as egg-fighting, buffalo fighting, bird-fighting and so forth are important aspects of Magh Bihu.

In the post industrial scenario, the symbolic enactments of folk festivals have been lost in translation. Assam, situated on the North east of India, is an amalgamation of diversified cultures and have been at the receiving end of both inter cultural and intra cultural influences. With the advent of globalisation, new cultural elements have emerged which shape the common way of life of communities. There is this urgent desire in individuals and ethnic groups to assert their identities through popular display of cultural elements. Globalisation has brought forth different dimensions of cultural identity as a repercussion to rapid change of social structure, mobility and loss of identity. There is a growing insecurity in these communities which has led to a competitive edge to the celebration of these festivals. Media has also played a major role in that aspect as they encourage people to display their identity through the various events that they conduct during these festival time. These have led to some popular culture creeping in the celebration of these folk festivals. A loud display of one's cultural identity reflects a community's presence in the backdrop of the cacophony of various other multicultural elements. Magh Bihu has transitioned from a folk festival to a popular display of cultural assertiveness as can be witnessed through the transformation of the humble Bhelaghar to installations of multi-storied structures. In the flurry of such influences on the identity of this festival of Bihu, certain cultural elements have transformed and emerged which provides new area for Visual Culture to foray into.

3.2 Festive Spaces

The Bauhaus understood that things could not be created independently of each other in space, whether movable or fixed, without taking into account their interrelationships and their relationship to the whole. To understand the fabric of urban form, knowledge of the concept of space and its interrelations is required. The formation of space occurs through these three elements of the model [6] (Fig. 1).

Urban spaces are ever changing, interpreting new meanings and form over time and history. India being on the threshold of global Urbanism has many unexplored avenues to look into to understand the changed roles and forms of urban spaces. The study of these spaces is important to understand the impact they have on human

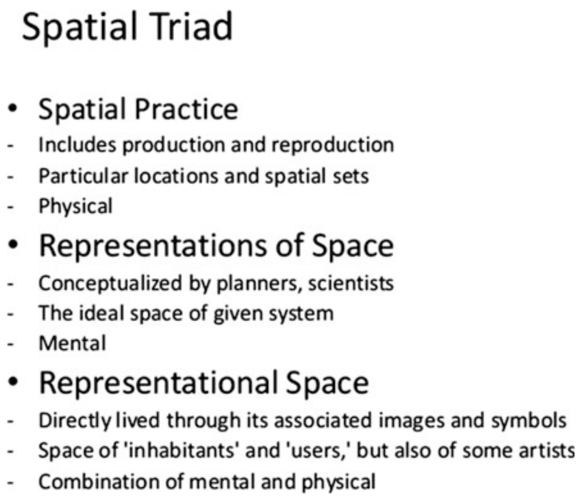

Fig. 1 Henry Lefebvre's Spatial Triad on Production of space [6]

interactions and behavior. Indian cities have two components that define their changing scenarios. They can be categorized as the Static City and the Kinetic City as Rahul Mehrotra mentions in his essay [5]. The Static City confirms with the traditional notions of looking at a city whereas the Kinetic City like the unruly child is dynamic, organic and often temporary in nature. Temporal and innovative are the keywords that define the Kinetic city. Festive spaces belong to this dimension of a city. They are temporal, dynamic and stretch the formally unimagined use of space in urban cities.

Silva and Chapagain [7] discuses the Asian heritage in the backdrop of traditional events and festivals. These events dramatically change the meaning and importance of a place or landscape. Often a neighborhood is temporarily transformed by informal construction as well as festive enactments associated with rites. Each community has its cultural space ascribed to such festivities. In general they are not well defined; yet during the celebrations the logic of traditional planning and use of these spaces comes alive, and the built environment begins to make much more sense. It is the temporary and informal transformation of built space, by which cultural memories are enacted and brought to life. These temporary and informal transformations of Asian cities through processions and decorations give spiritual significance to the city where the fixed built environment alone would not necessarily have achieved such a heightened cultural significance [7]. Moreover, the informal or kinetic urban is not necessarily an adaptation out of poverty but rather a creative expression of how space can be temporarily occupied in myriad ways and functions in dense urban conditions (Mehrotra 2007: 342) [5].

Spaces for festivals or performing rituals are not organized or part of the formal structure of a city and come under the category of temporal spaces. They are sometimes everyday streets transforming into sites for social interaction hosting communal gathering or sacred spaces with symbolic importance. Space needs activity and meaning to complete itself as a place. Festivals form the backdrop to understand a space through its special activities. These spaces can be indentified in the urban fabric as [4]:

(a) By default- spaces with historic meaning or cultural importance.
(b) By planning.
(c) By need: When a community feels the need to assert itself they create these spaces for themselves for the celebrations of their culture and rituals.

An interesting way these festivals are increasingly like brands is in their use of themes. These are increasingly used both as organizational and as an artistic device, allowing however a substantial degree of variation and interpretation. They provide a spiritual significance to the city where the static built environment alone would not necessarily have achieved such a heightened cultural significance.

3.3 Cultural Markers of Bihu

Symbolism is an important aspect of Visual culture. In Assam, Tamulpan, Xorai, Japi and Gamosa are four significant cultural markers of Assamese community and form an integral part of all rituals. These symbolic elements are offered as a display of devotion and respect and have their roots in the ancient aboriginal Austroasiatic culture (Fig. 2).

3.4 Transmutative Visual Culture-Magh Bihu

The site of study considered was the folk festivals celebrated in Assam, mainly focusing on Magh Bihu. A semi-urban setting was taken as the backdrop to understand the transforming character of the Visual Culture of Magh Bihu. This urban-rural setup offered an opportunity to understand the various inter and intra cultural interactions that take place during a festival. Bhelaghars have emerged into

	Artifact	Image	Traditional usage	Image	Contemporary usage
1.	Japi		Worn on the head as a protection against the elements (sun and rain). Offered as a sign of respect in felicitation ceremonies. Placed as decorative items in and around the house (especially near the front door as a welcome sign) There is a style of Bihu dance with Japi. A symbol representing Assam.		Although Japi is a traditional and historical craft of Assam, now days craft person, artisans, different artists across Assam have tried to immitate & explore the Japi fro traditional Bamboo craft to other materials like Bel Metal, Brass metal, Assamese traditional Jewellery in Japi form , in Assamese Traditional Textiles like , Hand woven traditional Towel 'Gamusa' an also in various Mekhala Chadars made in loom .
2.	Gamusa		Used daily to wipe the body after a bath (an act of purification). It is used by the farmer as a waistcloth (tongali) or a loincloth (suriya) Bihu dancer wraps it around the head with a fluffy knot. It is hung around the neck at the prayer hall and was thrown over the shoulder in the past to signify social status. Guests are welcomed with the offering of a gamosa and tamul (betel nut) and elders are offered gamosas (bihuwaan) during Bihu. It is used to cover the altar at the prayer hall or cover the scriptures. An object of reverence is never placed on the bare ground, but always on a gamosa. One can therefore, very well say, that the gamosa symbolizes the life and culture of Assam.		Gamusa is now available in various motifs and are mostly machine made. They have found their usage in other forms such as scarves, tops, etc.
3.	Xorai		Xorai, a traditional symbol of Assam, is a manufactured bell-metal object and an article of great respect. It is used as a container-medium while performing respectful offerings. As an offering tray for tamul-pan(betel nuts and betel leaves) to guests as a sign of welcome and thanks. As an offering tray for food and other items placed in front of the altar(naamghar)for blessing by the Lord. As a decorative symbol in traditional functions such as during Bihu dances. As a gift to a person of honour during felicitations.		With the advent of the global market new usage of the traditional Xorai has emerged. Some of them include Fridge magnets, Bamboo Xorai, Gateway design, etc.

Fig. 2 Comparative study of symbolic artifacts used in Bihu in traditional and contemporary context (*Image source* Google images)

the character of Public Installation Design as contrast to its earlier site of social interaction. From the small huts, these Bhela ghars have grown both in size and popularity as the media plays an important role in promoting them. As an onlooker puts it in his observations, in the year 2014, they made a Bhelaghar nearly 40 ft high consisting of five floors and because of its uniqueness instead of burning it down the next morning, it was retained for a week as the village saw many visitors from the nearby villages and town. This year encouraged by the enthusiasm of the spectators last year, the makers of this Bhelaghar added another floor which made it approx 44ft high. And if it was not enough they made another small Bhelaghar right behind this and attached both the ghars by a bamboo bridge. Apart from the gigantic proportions of the Bhelaghars, the villagers came up with the idea of installations depicting the social activities that they partake during Bihu. This included scenes portraying bird fighting, bull fighting and some other global elements such as a helicopter, a bird perching on a globe. These can be observed as the changing visual culture of Bihu. (Figs. 3, 4 and 5)

Fig. 3 Symbolic representations of cultural element Japi from Assamese culture depicted in the traditional Bhelaghar of Magh Bihu (*Image source* Author)

Fig. 4 Symbolic representations of cultural element from media inspired culture depicted in the traditional Bhelaghar of Magh Bihu (*Image source* Author)

Fig. 5 Different Bihu Melas (fairs) have started cropping up all over the city during Bihu celebrations. Apart from selling traditional Bihu snack items, they also provide a sneak peek into what the material culture of various tribes of Assam. These melas/fairs are playing their part in educating and making people aware of their culture and lost traditions. Some of them on the other hand include joyrides on pony and kite festival, which traditionally are not the essential elements of Bihu celebrations. This is seen as an impact of cultural exchanges (*Image source* Author)

4 Conclusion

Culture, in recent years, has become an integral part of the city taking on a more instrumental meaning. Festivals which form a part of the Intangible heritage of a city have now come to represent the ‘symbolic economy’ [8]. Symbolic economy focuses on cultural activities in various creative fields to contribute to the economy [8]. With the challenges posed by globalization and the rise of consumerist culture, cities are increasingly turning towards their cultural heritage to revamp their economy and image. Cultural festivals have thus become the prime focus through which cities are channeling their global economy and urban development strategy [8]. In the States of Andhra Pradesh and Telangana, the Government is officially promoting their religious festivals. Before the separation of the State of Andhra Pradesh, Ganesh Chaturthi was the only religious festival promoted by the Government [9]. Now in both the States of Andhra Pradesh and Telangana, various other festivals have joined the league [9]. This in turn have a huge impact on how festivals are perceived by people. With more money pouring in, these festivals have attained a huge stature and have transcended beyond the celebration of communities.

Thakurta [10] is one of the handfuls of scholars invested in the study of the visual culture of Durga Pujo. As she notes, Durga Puja reflects the changing mindset of the collective Bengali society in Calcutta [10]. Influenced by both popular and rural culture, an amalgamation of the new and the old is observed. This in turn is visible as visual motif through the display of the cultural elements borrowed from these multi-cultures [11]. With the involvement of the media and the desire for celebrity status, a competition among the sponsors becomes the prime focus [11]. These factors have largely contributed to the present spectacle of the festival [11].

Bihu, following in the footsteps of Durga Puja has much to collaborate to the cotemporary Visual culture of modern India. From a Folk festival, Bihu has now become a cultural spectacle with a hybrid culture even though it is a celebration by the agrarian community. Even though the symbolic meaning of Bihu has remained the same, this visual culture of this folk festival has metamorphosed beyond it to a celebration and exhibition of their personal creativity and influences.

Globalisation has brought forth a sea worth change of new vocabularies such as Multiculturalism and Interculturality, hybridity. Design is foraying into these new domains with the intention of exploring new paths for innovations. With globalisation, these folk festivals are transforming into new identities of Visual Culture. This will hopefully help the broader domain of Design research to understand the concerns of identity, sustainability and material culture of the artifacts of these indigenous people in the changing contexts.

The study of 'Magh Bihu' can form the backdrop for the observation and analysis of the emergence of new meanings and imageries of cities in the context of temporal events such as festivals. Silva and Chapagain [7] discuses the Asian heritage through traditional events and festivals and observes how they dramatically change the meaning and importance of a place or landscape. Mehrotra (2007) calls such temporal transformations of urban spaces the 'kinetic city' which holds 'associative values and supports lives'. The Kinetic City is dynamic and ever changing posing challenges to the study of the Urban form of cities. This has led to an ambiguity regarding the Urban form of present day Indian cities with new meanings emerging and no methodical study to understand them. This study can be further taken forward by analyzing the Urban form in the context of festivals. It can provide valuable insights in under-standing the process of a city's formation and transformation through temporal events such as festivals.

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Look at that Sound!—Visual Representation of Sound in Indian Comics

Subir Dey and Prasad Bokil

Abstract Sound is an invisible and intangible effect found in nature which is conveyed in different techniques in different media (films, novels etc.). Sound Symbolic Words or SSW are known as comprising of word categories that resemble or convey sound (audible as well as inaudible). As printed comic books have to rely on visual perception to create the sound inside the reader's mind, thus along with perception ability of the reader, her cultural exposure is also necessary in order to decode the meaning of the SSW. This poses a challenge to the designer to create words that signify the nature of the sound being represented. To create a visual representation of the sound it is essential to understand the syntactical structure of the words. Already the syntax of the SSW has been defined in earlier study [1], this paper aims to establish its relation with the meaning of the word. The SSW were categorized based on the semantic variables studied from a corpus of 40 titles and 1401 SSW. The results can be utilized by any designer to create SSW based on a given context.

Keywords Indian comics · Design · Semantics · Syntax · Visual representation

1 Introduction

The study of comics as a dichotomous ground of image and text is a ubiquitous trend which started in 20th century. Arguments and discussions have mostly revolved around the preponderance of text over image or the other way round. Most of the studies provide long discussions for comics' history, cultural value or its formal qualities. However, there has been a shift in focus from understanding comics as a form of storytelling to understanding its language in which it conveys

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the story (Cohn et al.). In comics, especially in printed comics, there are elements like image, text and sound symbolic words (SSW) that complement each other and create meaning.

The SSW's significance as a design element in comics is discussed in this paper. This paper also shows a preliminary analysis of the semantic attributes of SSW in Indian comics (Hindi comics) and their utility in relation to its syntax. There has been almost no study of comics in Indian context. The only dominant publisher considered worth for study was *Amar Chitra Katha* (*ACK*) and scholars have studied it from mostly visual cultural perspectives [2, 3]. This paper analyzes samples from Raj comics and forms the corpus of our study. The objective of this paper is however to understand the SSW and the meaning it creates in relation to its structure. The syntax is already defined in previous work acts as the signifier that signifies certain semantic categories explained in Sect. 5.

2 Representation of Sound in Comics

Language employs structure and grammar to communicate effectively. The language can be in the form of verbal, written or signaled communication. The visual language of comics also employs similar rules like linguistics [4]. While the image and its sequential nature is being studied closely in the recent years, the sound symbolic words or SSW have garnered little attention for scholars. Since the space inside a panel is very small therefore what goes inside it becomes of utmost concern as to maintain the communication inside the panel effective and undisturbed. Comics employs image, text and SSW to tell the narrative. Thus the SSW acts as a significant narrative element in comics. In this context, the sound symbolic words can be classified in three main categories [5]:

(a) Phonomime or onomatopoeia: The words that mimic actual sounds (like a dog's bark).
(b) Phenomime: The words that depict non-auditory senses (like smell and taste).
(c) Psychomime: The words that depict psychological or bodily feelings (like state of despair or confusion).

From the point of graphic design, the categorization of typefaces are based on text typefaces and display typefaces [6]. In the context of comics, cover titles and SSW come under display typefaces category. Thus it is important for the SSW to display appropriate contextual meaning to the reader. Onomatopoeias help to connect (in a panel) disparate elements of narrative images (like action lines, positioning, composition). They allow the reader to decipher the relations between action and events. In comic books they can either convey vocalization or sound effects [7]. While there has been much debate on the arbitrary relationship of signifier and signified [8], there are studies showing relation of the word and its visual form that posits that adults mostly relate (meaningless) word like '*maluma*' with a rounded shape and '*takete*' with a pointed shape [9]. Another study in Synaesthesia shows that nonsense words like *bouba* refers to a rounded shape while *takete* refers to an angular shape. This proves that sound and its shape recognition is not completely arbitrary and it is found in adults by nature [10].

In the study of the SSW, we identified a process for the generation of SSW shown in Fig. 1. The framework shows the five stages through which SSW could be created. The *Produced Sound* is the initial stage where the sound is originally rooted. The sound may or may not be an animated sound. But it has its roots in some object/action/movements. In this level, the sound is existing in invisible plane. The *Perceived Sound* is the level where the sound is actually heard or perceived by someone. The sound starts forming a mental concept in the mind and starts creating a conceptual shape of the sound. The perceived sound is then given a phonetic form in *Linguistic Representation* stage. The representation might not be

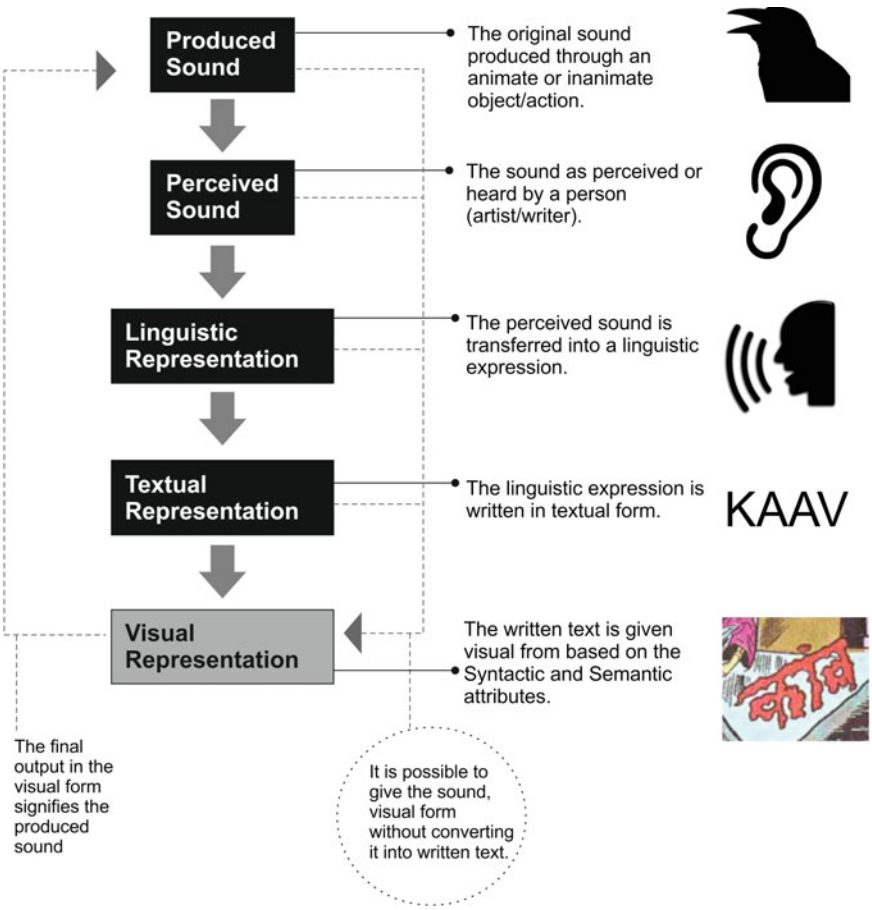

Fig. 1 SSW generation framework

same across different cultures. The sound then gets a written form in the *Textual Representation* stage. With the cultural conventions of a particular language, the phonetic form is given a textual form that could be read and understood. The textual form is the only form that is provided (in the scripts) to the comic book artist/designer while making the SSW. Finally, the text is converted into a visual representation that is known as Sound Symbolic Word. The final SSW thus created would revert to signify the produced sound. This is an extensive structure of the SSW creation process. However, it is not necessary that every artist/writer will follow the same structure. Sometimes conventions might allow the artist to directly create a SSW based on the textual descriptions. For instance, when there is an explosion inside a panel, the artist might select from already established SSW (*Boom*, *Badoom* etc.) and do not need to adhere to the above discussed process.

3 Samples from Indian Comics

Since this study was intended to analyze Hindi comics in India, therefore all the Hindi publishers were selected for initial study. However, it was found that Raj comics is the only publisher with exclusive range of superhero comics. This made it as an appropriate target for corpus collection. Our study then consisted 10 titles each of the 4 most popular characters in the Raj universe. The list of all the titles is given after Sect. 5. Superhero comics is a genre where it is obvious to find lots of SSW depicting actions and movements. For this study, the corpus was fixed on 4 most popular characters since their titles are more in numbers and widely read by a large number of readers. The corpus included 10 comic titles of each character with a total number of 40 comic books. The total number of SSW coded were 1401 across 2560 pages thus making the largest corpus study of Indian comics.

4 Categorization and Analysis of SSW

This study employs semiotic framework and observation driven methodology to enquire the semantic attributes of SSW. In order to create a solid foundation for comic theories it is essential to focus on specific level of comics. Focusing on a smaller area can give more insights and results instead of talking about comics in broader terms [11]. In this context our previous study already identified the syntactical attributes of SSW (like color, alignment, font weight and so on) [1]. Now, the syntax of SSW signifies some meaning in the context of the images. To identify what meanings are conveyed, semiotic framework was adopted and the categories were formed based on the signified concepts.

The SSW were categorized in 5 semantic categories: Living, Non-living, Action, Temporality and Psychological feelings. These categories were formed after analyzing each SSW and the kind of meaning they signify in a particular context (inside a panel). Since the samples were all collected from action comics, thus almost all the SSW signifies either action or living entities. Some SSW were also found to signify the time for the action in the panel. These were further categorized in SSW representing Instantaneous and Sustained time-period. Lastly, SSW generated some emotion while perceiving. These were sorted under the category of psychological feelings. The meaning making process and each category is discussed below.

In comics, SSW are always given visual characteristics that resonates the nature of the sound being signified. In the process of analyzing, the denotations and connotations of the SSW cannot be neglected. Being a visual form of sound, it can be said that both denotations and connotations are deeply embedded in SSW and in some instances even the SSW inside a blank panel could forward the narrative [12]. In Fig. 2, the first image shows a speech balloon and SSW for gunshots in a black panel. The image at first level is understood after reading the dialogues and the SSW. The connotative meaning lies in the nature of the word used. The word 'dhay' signifies sound of a small gun, repetition of words suggests firing form different directions and for a sustained period of time. These connotations will be understood by a reader who reads Raj comics and is literate of the visual style and the SSW for small guns. Thus SSW are very context specific and can take different meaning in various settings.

A hand-written SSW and a digital SSW can also give different effect. The second and third image of Fig. 2 shows an explosion. The SSW in the second image is digitally written and the third SSW is hand-lettered. While there is endless discussion on which mode is better (digital or hand-written), this example shows an instance where the difference is visible. The nature of an explosion is scattered, disoriented and loud. However, none of these qualities are visible in the second SSW. It simply appears to be pasted on the image. Also the color white is not a good choice to represent explosion and fire. The third SSW is visually better signifying the nature of an explosion. The shirorekha is absent, the letters are broken and scattered. All these connotative hints work together to give an impression of an explosion. This is not to say that hand-lettered SSW is better than digital SSW. However, this brings a concern for the appropriate function of both the modes. Both modes can be advantageous if used with its respective strengths. While hand lettering can give a unique style of an artist, digital SSW have the

Fig. 2 SSW showing gunshots and explosions respectively

options of numerous editing. It is the designer's concern to check for suitable methods and observe if the visual form of the word is signifying the action or not.

The SSW signify meanings in the narrative of comics. Especially when the genre is action comics, it becomes imperative to employ lots of SSW to properly convey the action. The analyses of the samples reveal the dual levels through which meaning is produced: the signifiers and the signified [8]. Semiotic framework is the basis of the analysis and study. In Fig. 3, the breakdown of SSW is shown in terms of signifiers and signified.

There are total 15 signifiers identified that were found in the samples. Note that there can be more signifiers in different genres of comics. These signifiers do not necessarily are present in all of the sample SSW however majority of them appear. Further, the signifiers were studied to identify the semantic categories they signify. The signs they represent can also be in any form like sound, letter, word, visual image, icon and so on [13]. Each SSW was analyzed and what category of meaning it generates was noted. For instance, a SSW signifying a gunshot signifies a non-living object (weapon) creating an action (in motion) and in an instantaneous

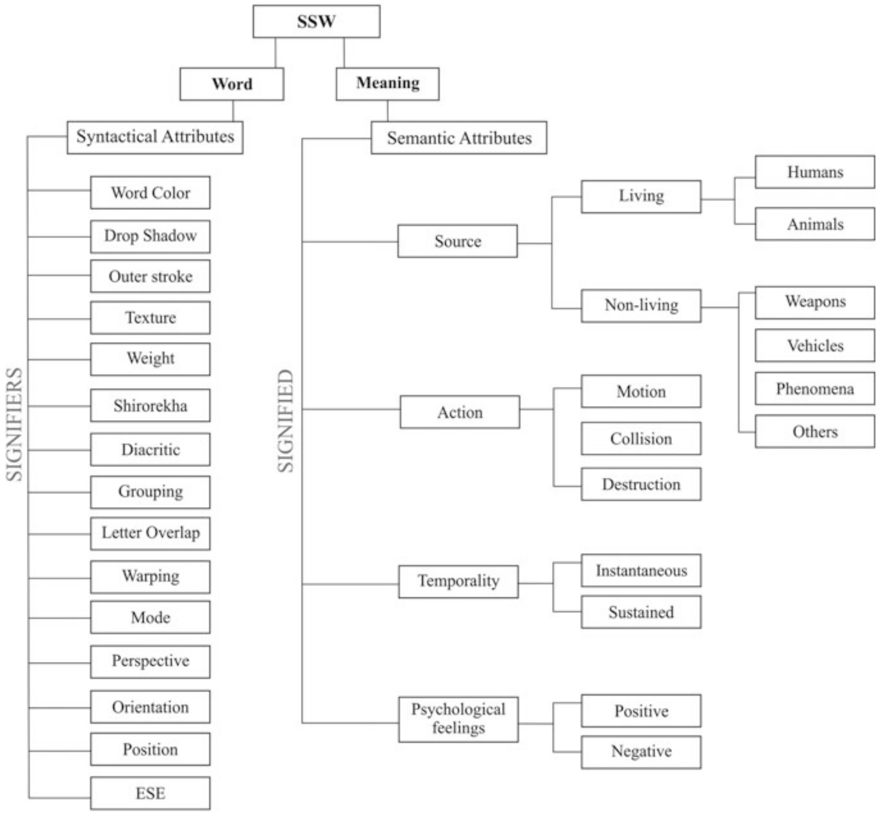

Fig. 3 Chart showing the signifiers and the signified in the meaning making process of SSW

time. It was found that out of 1401 samples, *Source* and *Temporality* accounts for almost 100% of samples, followed by *Action*-17.9% and *Psychological feelings*-8.2%. Discussed below is each semantic category with examples.

4.1 Source

The first semantic category was identified as the *Source*. All the sounds emitted (audible or non-audible) have a source from where it is produced. Thus, Source contains all the Living sources and Non-living sources found from the samples.

Living

The semantic category of 'Living' consists of humans and Animals. It covers all the SSW that signifies the sound created by (or due to) any human and animals (including all forms of life). This category was found to be the most inclusive since most of panels contained a living entity depicted in some action. It was also found that the visual style of SSW for humans and animals were not different. Even though they employed the same signifiers however the signified meaning is different denoting completely different entities. Figure 4 shows two examples of SSW. The first one signifying the sound of a punch. The signifiers like the broken Shirorekha, heavy weight of the font, and disjoined grouping of letters, suggest the nature of the punch and its effect. Like the receiver of the punch is disoriented and thrown off-balance, similarly the SSW also have a broken and disoriented structure. In the second image, the SSW signifies a barking angry dog. The signifier (Word color) is a gradient of red, orange and yellow. All of these are warm colors representing, anger, boldness and aggravated feelings. The diacritics are pointed and sharp signifying the nature of the dog and its bark.

Non-Living

The semantic category of non-living is divided in four attributes: Weapons, Vehicles, Phenomena and Others. Action comics employs different weapons in

Fig. 4 SSW showing a human punch and a barking-dog respectively

Fig. 5 SSW showing a gunshot, a car in motion, electric shock and musical bells respectively

fight scenes. These weapons can range from small arms to big machine guns and traditional weapons. Action comics depicts lots of chasing sequences thus the attribute *Vehicles* consists of all the SSW that signify the sound of a moving or stationary vehicle. The vehicles range anywhere between from a bicycle to a helicopter or spaceship. The third attribute, *Phenomena*, is a common category which might be found in any genre of comics. This category includes the SSW signifying sound of any natural phenomena like fire, waterfall, thundering and so on. The last attribute is *Other* category that includes the SSW that do not fit in any of the three categories discussed above. For instance, SSW for a musical bell might emote a happy feeling but it is originating from a non-living entity (the bell). Figure 5 shows examples of all the non-living sources producing sound.

4.2 Action

When a living or non-living body/object is moving from one point to other, then the action is considered to be signifying motion. When two or more living or non-living bodies/objects come in contact with each other, then the action is considered to be signifying collision. When the bodies/objects collide then there can be an effect of destruction. The level of destruction can be mild to severe (a punch hitting a face or a plane crashing on ground). Figure 6 shows SSW for motion, collision and destruction. In the first image, letters are repeated and this gives a sustained effect for the sound. The second SSW of a collision signifies a head banging on floor. Since the action is aggressive thus the red color and the sharp shapes of the text justifies it. The third SSW shows a bomb-blast. The letters are warped to give an

Fig. 6 SSW showing motion, collison and destruction respectively

effect of scattering. However, anomalies like the green color applied to a blast sound are also found in the samples. Through conventions it is mostly seen that warmer colors are more appropriate for signifying aggressive and loud actions.

4.3 Temporality

The actions inside a panel happens in a time line. Also, whatever goes inside the panel must have a purpose and aim that helps the action and narrative to move forward otherwise it's better to remove that. Here, SSW acts as a signifier to represent time of an action. Now, some actions might happen in a fraction of seconds (like a kick) whereas some might be sustained over a few minutes (a siren or dog bark). Figure 7 shows both type of time being represented. The first image shows a hand pressing and rotating a button. It will take few seconds to do that which gets represented through the single SSW 'klick' and the warping to signify the twisting motion. The second image shows policemen firing continuously. The SSW thus is repeated many times and starts from the left till the right edge of the panel. The repetition signifies the action taking place for a longer period and the sound resonating in the air from all directions.

4.4 Psychological Feelings

Psychomimes is the only category where only two types of SSW or symbols were found: the exclamation mark and the question mark. Figure 8 shows an exclamation mark positioned inside a thought balloon. This creates appropriate response for the reader to understand that the character is surprised or shocked. However, in the second image, the character is confused shown through a question mark positioned inside a speech balloon. Now, speech balloon essentially is used when someone has dialogues. In this instance what the character must be saying that is an ambiguity. It

Fig. 7 SSW showing an instantaneous action and a sustained action respectively

Fig. 8 SSW showing feeling of surprise and confusion respectively

is thus better to position question marks inside thought balloons instead of speech balloons for better clarity.

5 Discussion and Conclusion

This study is drawing towards a resolution to the meaning making process of SSW in Hindi comics. In this context the study identifies the signifiers responsible for the signified semantic attributes. It discusses the semantic attributes and the aims of employing those in comics. At first glance the SSW might appear just a piece of text on the image, but the study shows the SSW's function at a broader level to create meaning. It has a deliberate process through which it is generated and finally communicates a meaning. The SSW can be created through the framework shown in this study. While there are five stages of SSW generation, our study mainly focused on the visual representation of the text. The semiotic framework helps to establish the signifiers and the signified concepts in terms of semantic categories: source, action, temporality and psychological feelings. These are further divided in sub-categories that represent the range of meanings that a SSW generates.

In data collection, a point of concern was the decrease in number of Hindi comic book publishers. Due to this, the sample collection was restricted to Raj comics only. With most publishers now publishing comics in English, it will be difficult few years down the line to reflect on Hindi comics. Then, comics till certain period of time (with saturated diversity) will stand as a source of data collection. Another point of pertinence is the format of comics. With digital comics, it is now convenient to achieve range of effects that could enhance the artwork. However, since Devanagari script has been studied by few scholars with handful of fonts available in this script, it is found that a comic font or SSW in Devanagari has not been designed yet. The designers then have no choice except employing the fonts made for *reading* to use for SSW. This raises questions regarding the function of a specific font and its style. Whether a single font style is sufficient enough to convey the message in comic books? If not, then on what parameters it is decided to employ different font styles? Whether the dialogues, narration and the SSW should be represented in different font styles? How do these variations effect the semantic attributes of the image? What type of relation exists between image, text and SSW? And how do SSW contribute in the discourse of a visual narrative?

Comics are made for the masses. Every culture has their own cultural code to understand meaning. In this context, the choice of different visual styles of lettering can help to convey the essence of the sound [1, 14]. That's a concern for the comic book creators to look at. Only talking about comics in general and broad terms benefit little to this medium's understanding. This study thus invites Indian comic book artists to engage in serious discussion of comic's structure. It also poses a challenge to the Indian comics creators to create structurally strong works that could be noticed in global level.

Titles used for study

Doga titles: Genda #446/Chor Sipahi # 465/8:36 #2435/Tiranga # 40/Bombay Dying # 245/Naram Garam # 411/Main Bhi Policewala # 581/Ek Miyaan Do Talwaare # 348/8 Ghante # 138.
Nagraj titles: Shraap # 2432/Shakura ka Chakravyuh # 46/Nagraj aur Kanja # 35/Ronin # 2400/Nagraj ki Kabra # 19/Zehreeley # 102/Ambrish # 2426/Kayamat #189/Thodanga ki Maut # 444/Bauna Shaitan # 234.
Parmanu titles: Aag # 265/Mahamurda # 552/Parmanu Shakti # 115/Death Dot Com # 250/Jo Hoga Dekha Jaega # 2318/Blackout #276/Narak me Hain Parmanu #561/Parmanu ka Bachha #494/Aa Shakti Aa Parmanu # 175/Vidhwansak #266.
Dhruv titles: Super Commando Dhruv #485/Rajnagar Rakshak #2579/Mujhe Maut Chahiye # 193/Hatyaari Raashiya #53/Commander Natasha #64/Sheetan #286/Game Over #2419/Shadyantra #78/Hunters #2553/Awaz ki Tabahi #6.

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Legibility: Same for All Scripts!

Subhajit Chandra, Prasad Bokil and D. Udaya Kumar

Abstract This paper aims to identify the appropriateness of various parameters identified previously to define legibility in the context of Latin script done for the context of Indic typefaces like Bengali and Devanagari. The analysis is based on anatomical features, gridlines, letter binding, letter support, direction of stroke, stroke density, and variance. The paper also discusses various challenges of Indic scripts in terms of letter identification with respect to visibility and familiarity. Finally, various design parameters for identification are proposed for measurement of legibility of Bengali and Devanagari. The insight of the paper is to make type designers and researchers aware of effective design parameters that are necessary to understand during the design of Indic typeface.

Keywords Typeface legibility · Letter recognition · Letter features · Indic typeface

1 Introduction

A script is a visual manifestation of spoken sound and implicitly connected to its visual form [1]. Throughout the history of human evolution, distinguished sound quality of human culture introduces a large number of scripts worldwide. Distinct community or culture uses distinct letterforms based on explicit ideology or philosophy to develop their scripts. The identity of a script is apprehended by its visual form. Every comprehensive form of a script conveys certain visual grammar [2, 3].

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Thus, the understanding of the scripts is completely reliant on the script grammar. Legibility is the comprehensiveness of such script grammar.

2 Legibility of Typeface

Legibility of the Latin script is extensively studied in last century. There are many definitions of legibility available throughout the literature and these definitions vary significantly [4, 5]. It happens due to the engagement of different domain like ergonomics, vision science and psychology etc. that measure legibility based on the dominating factors in the respective field [4, 5]. The measurement methods commonly used in such studies are reading speed, comprehension, visual search task, eye movement, etc. [4–6]. Each investigation redefines legibility according to the need of study and such definitions create problematic consequence to define a standard one. In reality, there are too many variables that influence legibility to determine the outcome [7]. Now considering typography and type design, researchers explain legibility in many different ways. The few of the definitions are given below:

- Legibility is the measure of reading performance in correlation with visual variables of typeface [8].
- Legibility deals with 'the effect of different typographical arrangements on the reader's ability to carry out the reading task most easily, comfortably and effectively' [4].
- The term 'legibility' is used to measure the speed of reading, continuous text, visibility or perceptibility and familiarity of letters. To achieve the maximum legibility of letters, the varied conditions of such parameters are the major factor of recognition [5].
- Legibility is the quality of type that controls the perceptibility of a letter in the continuous text [8]. In other words, the distinctness of letters that makes perception easy to recognize.
- Legibility is the quality of being sharp and clear to recognize [7].

From the above definitions, it is clear that the legibility is the perception of the letters that deals with the explicable form and distinctive letter-shape. Legibility is measured by two operational factors such as visibility (recognizability of a single character) and familiarity (perceptibility or distinctiveness from other letters in the group). The visual factors like recognizability, distinctiveness, and clear appearance are the measure of legibility. The measurement of such factors is proven to be dependent on anatomical features and typographical parameters such as ascenders, descenders, x-height, contrast, stroke weight and width, counter, stroke path and etc. [5, 6, 9–11]. Many times such inferences have been adapted to define legibility of Indic scripts without validation. Such adaptation of framework is required justification to establish the knowledge of legibility with respect to Indic scripts that may or may not be the same.

The significance of legibility studies is to measure the impact on reading by maximizing the chance of getting recognized [7]. It is reading research where visual and cognitive methods deal with typeforms, contextual and cultural factors. A single letter of a script is nothing but a visual form and the construction of that letterform is explicit [12]. Each visual form is an association of global and local features that confines the letter-shape at a certain point. Therefore, approach to the legibility of the letterforms across all scripts may or may not similar since most of all letters are a combination of local and global features. Legibility studies need an investigation considering typeforms across all scripts or based on similar scripts.

Legibility of non-Latin typefaces is not widely discussed topic in the research community. Most of the rules and regulations are adopted from Latin only. It’s only in the last few decades that researchers have started empirical research on non-Latin scripts [13] which is very sparse in literature. Here, Bengali and Devanagari scripts are taking into account for the study considering the limitation of the paper.

3 Legibility and Visual Form

The visual form of a letter conveys the complete sense of type construction and communicates a specific sound as its meaning. Visibility is the measurement of such communication [5, 11]. Every letterform is a collection of certain letter stroke, also known as letter features [14]. The combination of such features completes the identity of letters. The process of letter identification follows the Gestalt law of good continuation that involves grouping of features [15].

The legibility researchers are also argued that if most legible letters of the different typefaces are considered to create a word structure that might not be the best solution [16]. The effective legible text may be created by introducing letters belonging to same typeface family [5]. A comparative visual analysis of groups of common letterform of any two scripts can provide the insight about the difference among these scripts. Figure 1 illustrates the groupings of common letterform in Latin and Bengali scripts. A single group (such as ‘Round forms’ or ‘Diagonal forms’ in Fig. 1) is not enough for both Latin and Bengali scripts to fit their letters due to the varied construction of letterforms. A different approach to Bengali like ‘Grouping of Common Structural Letterforms’ (as in Fig. 1) would be more reliable approach than adopting the existing. Their unlikelihood is raising doubts about the adaptation of legibility rules of Latin.

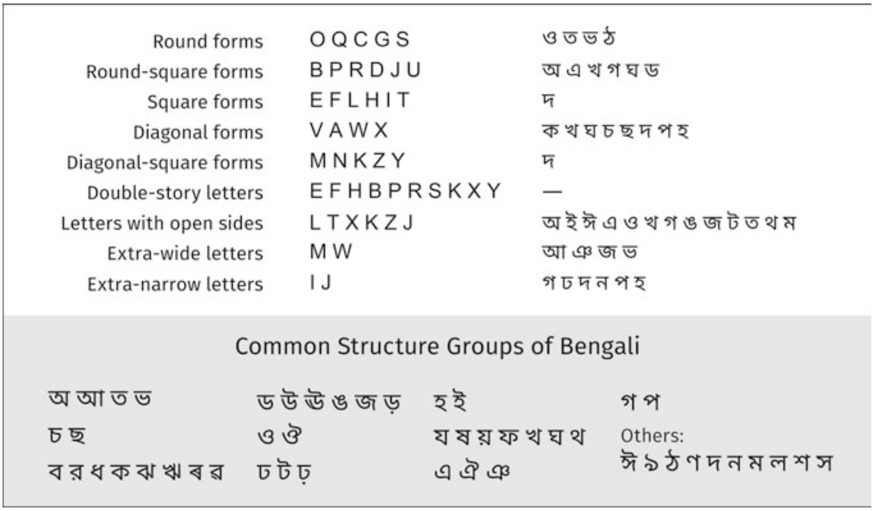

Fig. 1 Structural formation of Bengali and Latin

4 Parameters Affecting Legibility

Legibility used to measure by reading speed, visual search task, eye blink and others few techniques. Such studies majorly have been done in ergonomics, vision science, and other areas. But, those studies never considered the design variables like Gridlines, Stroke Width and Weight, Stroke Path and Treatment, Stroke Density, Terminals, Optical Size, Stroke Contrast, Proportion, Structure, and Counter [5, 6, 17]. Recent studies are focusing on such factors through tests like short exposure test and distance threshold test [5]. However, such tests are never applied to non-Latin to measure legibility. There are different rules for print and digital Latin typefaces but such rule base varieties are not there for the non-Latin typeface. This paper will demonstrate the critical issues with these variables with a comparative study of Bengali, Devanagari, and Latin scripts.

4.1 Unique Features of Indic Scripts

Conjuncts. Conjuncts are the single letterform of two or more consonants and/or vowels connected vertically and/or horizontally (Fig. 2). The conjuncts of Indic letterforms are mostly two or more tier design which is uncommon to Latin letterforms [18]. The height is a crucial factor considering the multitier structure of letters. If the vertical or horizontal clearance of letters is not enough, they could touch the next (or previous) or below (or above) character (as in Fig. 2) which is also known as 'Crowding' [19]. Crowding is a phenomenon when two or more

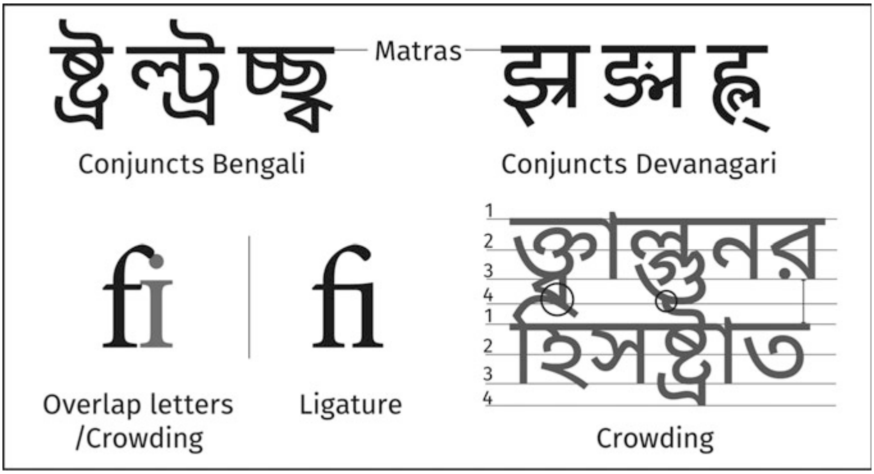

Fig. 2 Multitier letters and 'Crowding' occurrence

outlines (of strokes) touch each other. This is one of long standing issue that needs a solution.

Conjuncts are not similar like Ligatures[1] in Latin but to achieve a certain sound. Sometimes, their combined form may appear in the completely different form. Therefore, the perception of those conjuncts is completely different than ligatures in Latin although they appear in a single glyph. Such letterforms need a systematic study to establish distinctiveness and to achieve legible structure.

Matras. A Matra is a horizontal stroke that confines the letter in case of Bengali and Devanagari. Almost every letters and conjuncts have Matras from which the main body of the letter hangs towards below (Fig. 2). This feature is never considered as a standpoint to analyze these letterforms that may provide insights about the legibility issues of Bengali and Devanagari.

4.2 Gridlines

In typography, the gridlines are an arrangement of fundamental horizontal lines that construct the size and vertical proportion of the letters (Fig. 3). The standard Latin grid system consists of five major lines i.e. ascender, cap-line, x-height, baseline, and descender. Their parallel distribution (horizontally) ratio defines the purpose of the typeface. The display typefaces have greater x-height that enables readers to read lowercase letters more efficiently. Now, such gridlines are used for any

[1]Ligatures are the juxtaposed single glyph of two or more letters in case of Latin. It consciously designs to eliminate the 'crowding' of two or more like 'fi', 'ffi' or 'ffl'.

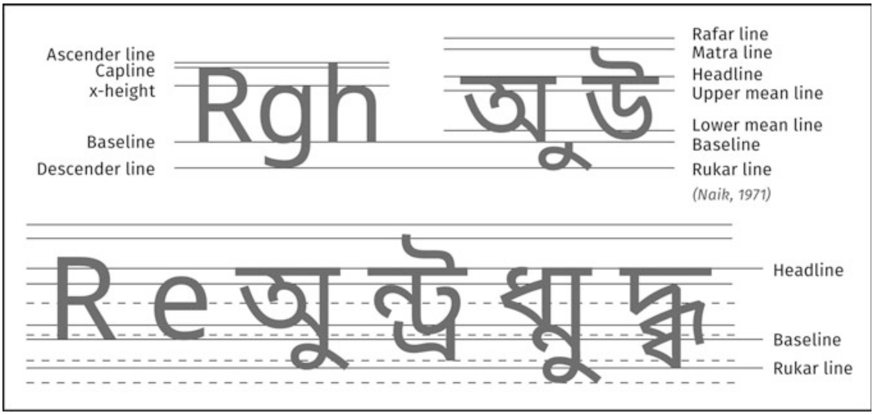

Fig. 3 Comparison of gridlines

typeface irrespective of Latin or non-Latin across most of all font development software. This adaptation of gridlines for non-Latin typeface may not be an effective approach. Indic scripts do not have any ascender or descender instead they have ‘Matras’ and dependent vowel signs. Also, they do not have any concept of uppercase and lowercase letterforms. Thus, the concept of cap-line and x-height is completely misinterpreted in Indic typefaces that affect the letter proportion and further the quality of typeface. Therefore, the question of the recognizability or visibility of such letters can arise.

Naik (1971) proposes a grid system of Devanagari scripts. It identifies seven different gridlines according to structural formation and body proportion of letters [20]. But the vertical proportion of the letters significantly varies with respect to these gridlines (in Fig. 3). The proportion of every letter changes accordingly most of the time. Thus maintaining a constant ratio among these gridlines is a problematic one (like Harsh-U’, last one in Fig. 3). In addition, the nature of Latin letters is standing on baseline whereas the Bengali or Devanagari is like hanging from their ‘Siro-rekha (Matra line)’ (in Fig. 3). Thus, the use of such gridlines for non-Latin needs a validation and a standard procedure of use or a completely separate grid system in practical.

In addition, the multitier characteristics of conjuncts also suggest a need for modification in the grid system. The standard grid model is, proposed by Naik, may fit for vowels and consonant but it is not enough flexible to fit the conjuncts [18, 21]. Even three or four tier letters are more complex and they never consider in gridline studies that may possess a standpoint for analysis [21].

4.3 Letter Stroke

Letter strokes are the unit of letter construction. It is also known as letter feature which is crucial for identification purpose. The distinctiveness of letterforms occurs due to combinations of stroke or the varying combination of stroke junction also known as joinery. Stroke unit and joinery both together make letterform distinct identifiable from other. Considering the significance, variables related to stroke are discussed in below section.

Stroke Path and Treatment. The stroke path is the identifying characteristics of letter whereas treatment is the design specification of the letter stroke (Fig. 4). Both together enable the readers to identify the letters and the family that letter belongs to. Both stroke and treatment are contextual and culturally rooted. The history of a script has great impact on design development of typeface. The Indic scripts are majorly dominated by writing tools. The impression of the tool is clearly visible on the construction of the letterforms [2]. Without knowing that blending of the tool and cultural practice, the design of the letterforms may not achieve desired quality or richness. Therefore, it can be further discussed the influence of native and non-native designer on type design process [22] in the context of multilingual typeface design and legibility of typeface.

Stroke Contrast. Stroke contrast is the ratio of thinnest to thickest stroke. One can find typefaces with very high contrast to mono-linear (Fig. 5). High contrast typefaces are traditional design primary used in print media. Mono-linear typefaces develop in digital era targeting screen reading. Since, Bengali or Devanagari scripts are dominated by writing tools like cut nib, flattened nibs angled towards left and right, square and oval tips, split point nib, calligraphic brush and etc. [2, 18]; the high contrast stroke is an incorporated feature of these scripts [2]. The development of monolinear design for such typeform may need an explanation. At the same time, design validation of such typeform is also needed comparing its original form.

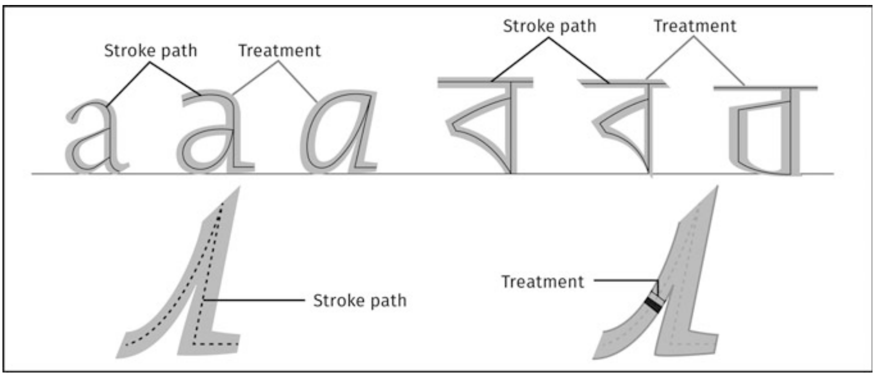

Fig. 4 Stroke path and treatment

Fig. 5 Stroke contrast

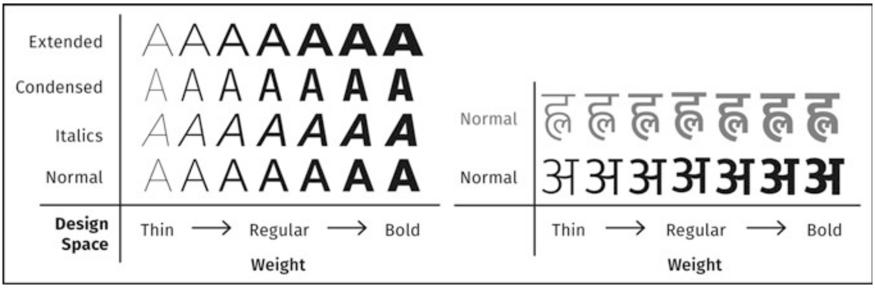

Fig. 6 Distribution of stroke weight in Latin and Devanagari with conjunct

Stroke Density (**visual density**). The stroke density [7] of Indic scripts is higher than Latin and it becomes much higher in the case of conjuncts. The letters are sinuous with complex structure. Every letter has to design within a given space, allocated in font design tool, also known as ‘letter space’. It is fixed horizontally for all letters within a font but only vertically adjustable. Thus, the space management against a letterform is a key concern since most of the font design tools set for Latin specification. The vertical to horizontal ratio need a precise distribution that should not distort letter proportion (Figs. 5 and 6). So, there is a scope for developing systematic space distribution or management system for Indic scripts.

Stroke Width and Weight. The stroke width is another issue that needs attention since the stroke density of Indic scripts is higher. To maintain familiarity within all letters, the stroke width has to be at optimal magnitude by which every character can be designed without any distortion. Also, the linear or exponential increment of stroke width (every instance of stroke width is a single weight) is possible that will further lead to the creation of type family (Fig. 6) [21]. Such complexity of design leads to limit the design for only single weight or few variations in weight in contrast to Latin type families.

Fig. 7 Terminals of Latin and Indic Scripts

4.4 Terminals

Fiset et al. [23] conclude that the terminals are most important features for letter detection (Fig. 7). However, this study, as well as few others, is based on Latin script. The letters with terminals and their 'Finial (appearance of the terminal)' are few in Latin like 'a', 'c', 'e', 'f'. Whereas, in the case of Bengali and Devanagari; there are many letters with terminals that end in different direction. Therefore, the significance of terminals and its importance in the legibility of these scripts are needed to be investigated and reinstated with the proper contest.

4.5 Optical Size

The Latin letterforms are mainly geometric (Fig. 8). They are based on three basic shape triangle, square, and circle. The tip of the triangle is called 'Apex'. The most upper and lower extended point are called Overshoot (exceeding cap-line or x-height) and Undershoot (exceeding baseline) respectively [1]. The over/undershoots are 3–5% prolonged to avoid optical illusion (otherwise, it will be looking smaller than others) (Fig. 8) [1, 3]. The construction of Bengali and Devanagari letterforms are sinuous which is completely different than Latin letterforms. Most of the main letter parts are hanging from a headline or 'Matra' [20]. Therefore, the optical balance of such letters should be done considering 'Matra' and the main letter-part. A refined study requires to establish optical balance and rules for these letterforms.

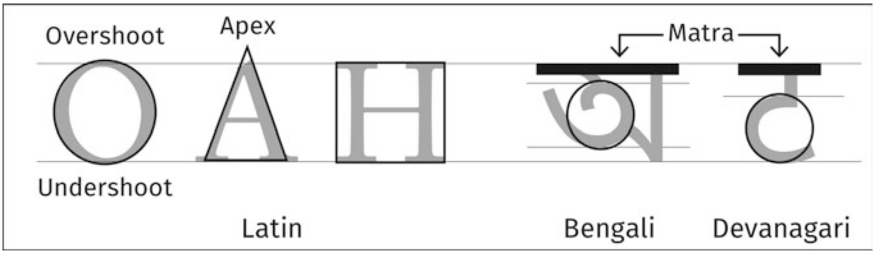

Fig. 8 Basic structure of Latin, Bengali, and Devanagari

5 Conclusion

Legibility measure is a systematic approach by considering the design, visual and cognitive factors together to maintain a certain quality of appearance of typefaces. Considering the above discussion on Latin and Indic scripts like Bengali and Devanagari, it can be concluded that legibility of Indic letters depends on the script grammar, structural formation, letter cognition and as well as the medium of text displayed or represented.

Legibility is definitely dependent on physical parameters of letterforms just as clear representation and identification of letters but it is also influenced by the evolution of script and design process of the letterforms. This paper highlights the lacuna in the current paradigm of legibility borrowed from Latin study but it does not propose a new paradigm for Indic scripts. A thorough enquiry of design parameters with various cognitive and cultural aspects is required to propose a new approach to the legibility of Indic scripts. Such extensive analysis is out of the scope of this paper. But, the observations drawn here may draw the attention towards the need of research in the context of legibility of Indic scripts.

The approach to legibility may not be entirely similar for all scripts. Otherwise, there will be no problem at all with the legibility of Indic typefaces if it is same as Latin. But currently, the discussion clearly suggests that there is a problem with the legibility of non-Latin typefaces. To solve the problem, a systematic method of contextual enquiry may be needed. Besides, sophisticated equipment and efficient research techniques are also required to measured letter legibility considering all significant aspects.

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A Preliminary Semantic Study on Communication and Perception of Energy Meter Graphics

Venkateshwarlu Varala and Pradeep Yammiyavar

Abstract This paper presents a study of Indian user groups based in rural and urban India for the users' perception of different electricity meters interfaces in terms of their perceived usefulness to save energy, how meaning full they are and how user centric is their communication ability. This paper discusses the semantic construction of meaning in products specific to Graphical User Interfaces and through a visual perception user study it intends to understand Indian GUI usage scenario. Inferences drawn contribute to heuristics of graphic user interfaces of flat screen displays of next generation energy meters.

Keywords Graphical User Interfaces (GUI) · Meaning · Perception · Semantics

1 Introduction

According to product semantics primary function of any product is to communicate their use through different features such as form, shape, color, and graphics. For a successful communication these features forming information cues, need to be within the perceptual limits of their target users. These information cues could be visual, tactile, sound based or combination of all at once depending on the product. When product designers combine these cues consciously to propagate a message, products create an affordances [1] for their users. So a product is basically trying to communicate its usage. Whether the design is intentional or not products propagate some kind of message. While on the other side when the user encounters the product they perceive, try to understand, and use or interact with it. This entire process resemble the model of a classic communication system [2] where the designers are source of Information, products are transmitters the users are desti-

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nation of the information. For any successful episode of interaction, the intended meaning of the design has to match the evoked meaning of the target user groups. This paper aims to understand the gap between perception and meaning.

Products such as computers, mobile phones etc. communicate through a User interface. Visual Interaction with these interactive information systems takes place through a Graphical User Interface (GUI) display screen. While there are several other ways to interact with such devices, GUIs are the prominent ways to interact visually.

India is one such scenario where the use of such technological products with GUIs as their interfaces for communication is becoming more and more common, how these products are a serving a diverse user groups in India is of interest to interaction designers while taking care of meaning related user requirements. In this paper one such device that is part of every household—be it rural or urban is the electricity energy meter and its User interface.

2 Literature Survey

An interface takes shape by the way the information elements are stitched together in right composition with the designer intuitive skills besides the heuristics to construct and communicate a collective meaning to their target user, hence it is important to understand how this is done with respective to the graphical user interfaces.

According to theory of communication, meaning in linguistics [3] is an expression by a sentence which evokes a sense of understanding to its receiver at a given context. When referring to the literature on the meaning in products and designing products for meaning there are multiple theories associated to it with the boundaries expanding into many other disciplines.

Product semantics [4] is the field of study which deals with the semantic construction and analysis of real world objects such as a visual/artefact. Krippendorff and Butter R are the pioneers to introduce the concept of product semantics and they define it as “a vocabulary and methodology for designing artifacts in view of the meaning they could acquire for their user and the communities of their stakeholders” [5].

Semiotics [6] on the other hand is a subject that deals with the study of signs where its application in product design based on the linguistics principles of treating every communication element as a sign systems. Product semantics differs itself from this notion of applying two dimensional sign principles to the three dimensional concreate objects. Two major semiotic theories which are used for semantic analysis of products are triadic theory [6] by Charles Peirce and dyadic theory [3] by Ferdinand de Saussure.

Both of these theories are being applied in interface design over the years.

The object of study in this paper—electric meters have so far been dominated by graphic elements namely numerals to communicate energy consumption. Meters of the future are expected to have many graphic elements and not just numerals. A study to understand how Indian users perceive the existing numeral dominated GUIs is a starting point to anticipate how the next generation meters need to be approached by an interaction designer.

Understanding GUI Design:

Graphical User Interfaces of information systems communicate their function by making use of visual elements such as Icons, widgets, text and color, animations and various other representation. Here these visual elements are represented metaphorically to communicate the machine functions to understandable visual user language. When All this elements come together collectively into the user perception they evoke a meaning as it shown in Fig. 1.

Anything that is visual and perceptible, contributes to the right meaning making when that specific element has the right cues with all the required sub elements with it. For instance an icon with the text, or an icon itself.

This interpretation of information starts with the cognitive process of perception as shown in Fig. 2.

The communication will be a successful episode of interaction when the user mental model is a match with the designer intended model evoking the right meaning (Fig. 3).

Literature findings [7, 8] shows that the perception is greatly influenced by the factors like the user cultural backgrounded and context of use. As How these devices are semantically communicating the meaning they are supposed to communicate, while taking care of diverse cultural variations and contexts of usages of Indian user groups is not yet explored fully. To know how the electricity energy meter GUIs are interpreted by Indian user groups with a preliminary user study has been carried out.

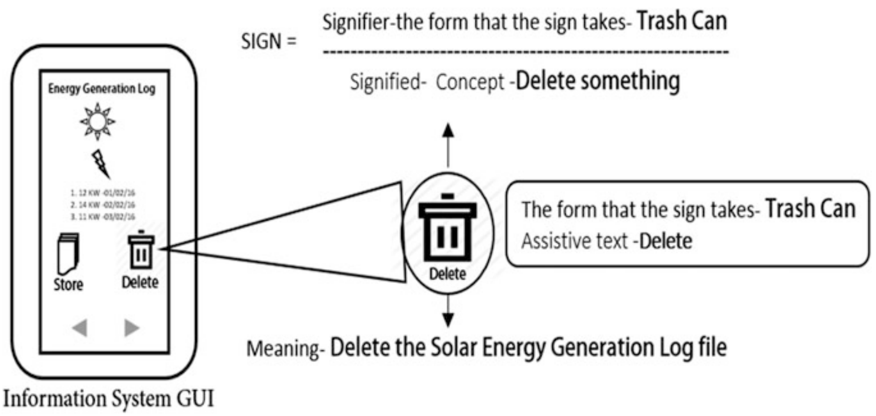


Fig. 1 Communication elements in GUI

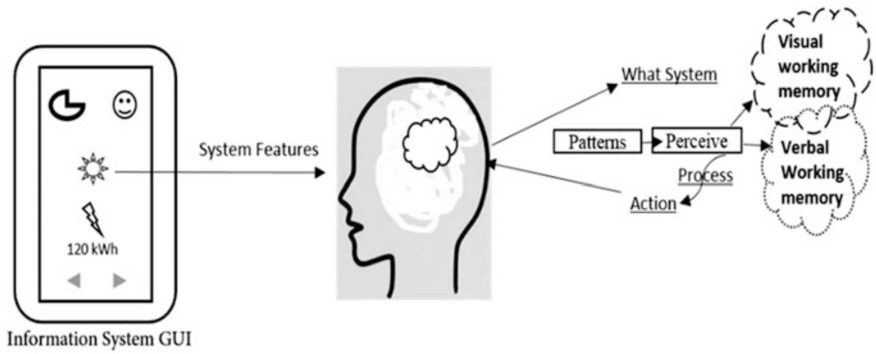


Fig. 2 Cognitive process of perception (Adopted from Information Visualization, Colin ware, 2002)

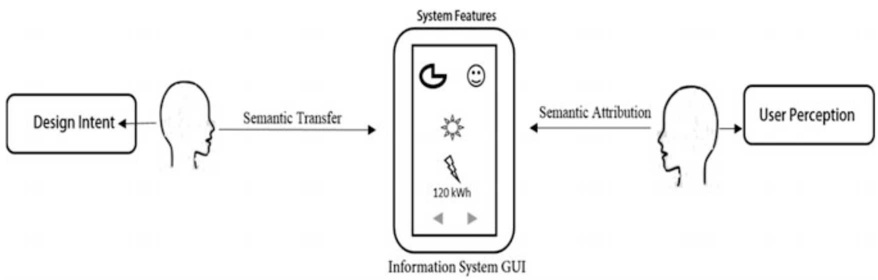


Fig. 3 Showing semantic transfer and attribution

3 Exploratory Study on Indian User Groups

A study was conducted to know perception of the energy meters and their ability to communicate the meaning across various user groups. For the study six electricity meters were chosen randomly.

3.1 Subjects

Twenty six participants of an age group of 20–60 years participated in the experiment. Subjects belong to different geographical regions of India. The minimum criteria for the participants are, Indians with minimal exposure to any energy meter available in their households. The details of the subjects and their backgrounds are mentioned in Table 1.

Table 1 Subjects

Subject user group	Gender division	Number of subjects	Geographical location
Engineers	5 male-2 female	7	Different parts of India
Housewives	5 female	5	Different parts of India
Farmers	7 male	7	Assam
Designers	5 male-2 female	7	Different parts of India

3.2 Stimulus Preparation

High resolution photographs of selected six electricity meters were photo printed with uniform resolution, pictures of the stimulus are shown in Fig. 4. Except for the Meter 1, all the other meters are smart energy meters. Each one of them were selected with improvements in technological features, screen size, richness in graphics from one to another.

3.3 Study Procedure

This study is based on the semi-open ended interview method with users coming from across different stratum. In this process people from different user group (Fig. 5) were interviewed with guided questions. All the interview responses were transcribed and audio recorded. Guided questions were drafted based on the cognitive process of human Information visualization and perception.

Fig. 4 Stimulus used for the study

Fig. 5 Subject interviews

RQ1. Did they identify and associate to the product in the first encounter and what did they think about the product?

RQ2. Did they understand the Information present on the screens?

RQ3. Describe the appearance?

RQ4. What did they feel about the product?

Apart from the above specific question subjects were engaged in open conversation to describe more interpretations of the products. They were also asked to describe their experiences with the meter they have been using or familiar with. Every subject was interviewed for an average time 30 min each. Total time taken for the study is close to 780 min.

This study was conducted with larger intent. The study was conducted to understand user perception about the meaning, user preferences like/dislikes, emotional responses, aesthetic preferences and perceived ease of use, language preferences. Here in this paper only the analysis of responses related to the visual perception and meaning are reported and discussed.

3.4 Data Analysis

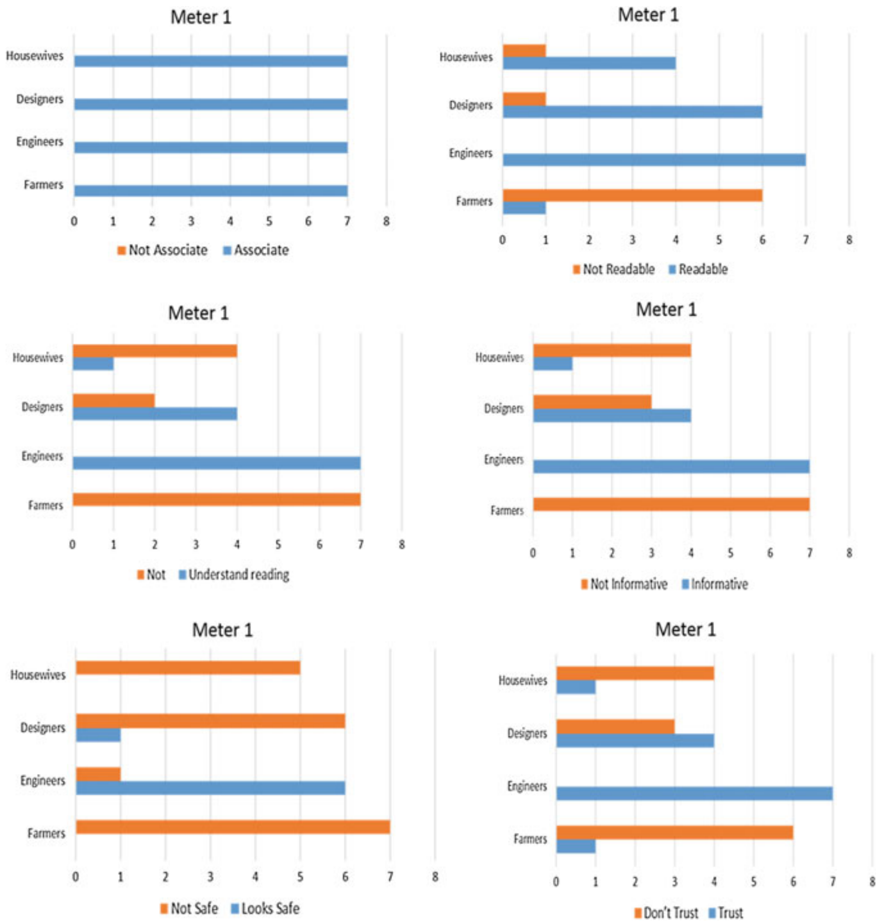
Analysis was carried out using content analysis approach, analyzed responses were coded with an aim to quantify them and they were counted for their repetition.

3.5 Results

Below are the most repeated attributes found from the analyzed data related to the basic visual perception and meaning.

Associate to the product—Not: Readable—Not Readable: Understand—Do Not

Informative—Not Informative: Looks Safe—Unsafe: Trust—Do not trust



Graph 1 Meter 1 responses

Graphs with respective to the meter 1 mentioned here below, cumulative results are discussed in the inferences (Graph 1).

In addition a semantic feature analysis [9] was carried out as bellow involving various graphic elements on the meters such as, color, typography, size of fonts; placement and layout of elements with respect to overall screen; ease of reading, visual order, overall aesthetics; relatedness to each other and grouping. The extracted feature from the analysis are mentioned on the left side. The most occurring features are circled and given weightage as shown below. For example 'numerical reading' is the most occurring feature with respective to all the meters given below. This analysis was carried out to support the inferences from the user perception study (Fig. 6).

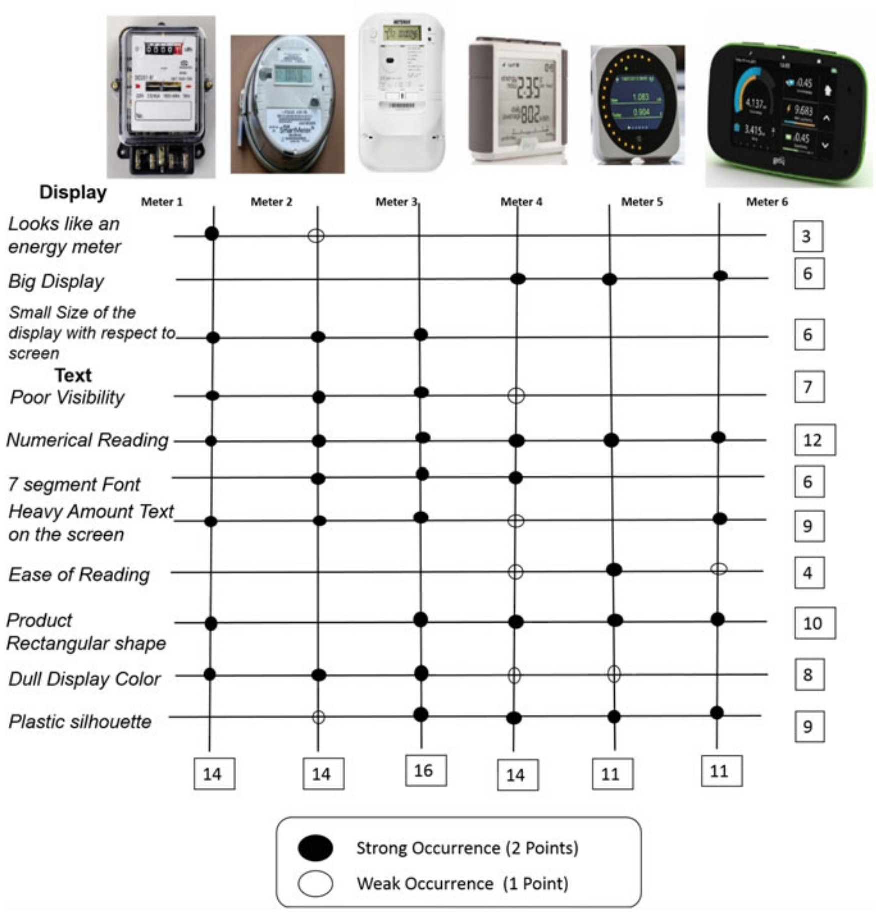


Fig. 6 Semantic feature analysis of the meters and comparison

4 Inferences

Inferences are drawn from the analyzed data are categorized into the four groups and discussed here below

Farmers Category:

From the analysis of the data it is inferred that this user group was able identify only meter 1 due to the long exposure/familiarity but none were able to identify other remaining meters. None of the users knew the actual meaning of the reading and most of them do not read since they fear to approach it, majority of the users do not know how to read them for correct interpretation, the graphics on the interface is not helpful in interpreting the meaning. They feel these products are not safe to approach though the modern ones are completely safe, and they do not trust the meters when it comes to the monthly billing and the way they function. This user group is more concerned about the monthly bill, and interested to know proper representation of the consumption in an easy way they can understand, than the engineering reading which does not make any sense to them.

Engineers Category:

This user group is able identify and associate to all the meters they understood all conventions, graphics and readings, except for the aesthetic dislikes they did not find any meters ambiguous. They felt the presence of the tariff/fare is an added advantage but not mandatory but the absence of engineering kWh reading is a complete no for them and it is less informative. All the engineers feel safe about products and trust them for their functionalities.

Designers Category:

This user group is more aesthetically sensitive. Designers without technical knowledge did not understand the technical conventions and graphics. More interested in suggesting the design changes that can be made to look products more safe, informative, meaningful and useful. Trust in products is variable. Due to professional instincts they were more in designers' role than a user's.

Housewives Category:

Housewives without the technical knowledge have similar response to that of farmers. More interested in knowing the household consumptions and suggestions to save the energy, interested in fare more than the just a numerical reading. Most of the users of this groups rarely use/have less exposure to the household energy meters. They fear in approaching the meters.

The users who have understood the information other than engineers are the one who had the technical knowledge. From the semantic features analysis it is evident that the most accruing features are influencing the perception and meaning as mentioned above.

For instance the most occurring feature is numerical reading which is not understand by majority of the users groups.

5 Discussions and Conclusion

From the above study it is evident that the meters tested here are not very appealing to the users and in some cases the users really don't connect with them as products. These GUI are built on the basis of conveying the engineering information and quantities rather than communicating energy consumption. Except for the engineers, majority of users from other groups perceive them as less safe, untrustful and find them less informative, while farmers user group do not associate with them in the first place. When we see it from the information design perspective it is the mismatch between user mental model and designers.

Emphasis on the meaning should be given paramount attention since the penetration of this products to the market is growing at a faster rate than the social cultural changes and adaptations. For instance, an electricity usage meter for a 'farmer' needs to be much more than energy billing and electricity consumption indicator. It is the water that is pumped and not the electricity which in the perception of the farmer that needs conservation, such a requirement from a farmer is more of cultural and contextual in nature. From this study it is evident that all six energy meters are depicting information based on engineering parameters of electricity that make no sense to the user be it a farmer or an urban housewife. A next level energy meters has to be radically different from the existing ones, a synchronicity to be brought in between semiotics of the elements, semantic meaning and gestalts in the future meters with in the cultural contexts.

Studies indicate [10] that semantics of visual cues and metaphors vary across strata within cultural groups and may have a contributing role in influencing and increasing the bond between a user and utility value of a particular group. It is posited that digital smart meter interfaces that are intended to be deployed widely in India in the near future, will require communication interfaces that are customized according to user segments.

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Applying Product Semantics to Benchmark Physical Properties of Product Characters Through Design Teaching: Strategies for Shape Coding

Shujoy Chakraborty

Abstract The novelty of this study was to throw light on physical properties or intrinsic features which influence the communication of a product character and the teaching the skill of manipulating such properties to product design students. The paper benchmarks successful strategies for shape coding: *playful, simple,* and *modern* characters. These characters were selected because existing literature has claimed them as appearance attributes (product characters) universally recognized by ordinary users (non-professional designers) and expert users alike, resulting in their higher success rate for meaning communication. Although existing literature has explored relationships between product characters and physical properties using statistical and mathematical tools, this research attempts to establish that relationship from a more practical and hands-on approach by having Designers in training (students) develop design strategies through product forms. Professional designers and theoretical academicians regard product semantics in fundamentally different ways, where, designers tend to depend more on intuition and experience seldom using qualitative tools when dealing with meaning communication through form giving. The teaching discussed here contributes to bridge this gap by introducing a design process to students (designers in training) based on language structures while shaping intrinsic features of a product form.

Keywords Product semantics · Product character · Intrinsic features · Meaning

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1 Introduction

Product Design communicates meaning to consumers [1], and consumers derive this meaning through a product's physical properties [2]. This paper will investigate how meaning communication happens in products through the physical properties which make up their character or personality. Existing studies [3] have investigated how products reflect their character or personality [4] based on physical properties of their form. This research should be seen as a step further to encapsulate that research through a more hands-on and empirical process. Blijlevens et al. [5] have pointed out that the 3 product characters which they extracted empirically were stable and successfully read across diverse household product categories. The next step in their study points to the direction of extracting the *physical properties* which underlie these appearance attributes so that they are more tangible and relevant for designers to work with i.e. *objectifiable*. This research attempts to build this next step of their on-going work by highlighting a teaching based process consisting of specific tools which the author used to achieve this *objectification* of the product characters discussed.

The validity of the physical properties or intrinsic features extracted in this research have been tested by designing diverse handheld product categories in a studio teaching environment. Existing literature has pointed out the care which should be taken to diversify such studies across different product categories in order to avoid the results being too category dependent and not generalizable [3, 5].

2 Literature Review

Consumer behavior and design literature streams are analyzed in this paper for concepts relating to meaning communication and product semantic theory. The variation in definitions coming from each community can throw some insights into the research contribution of this paper.

2.1 Product Semantic Theory-Basic Concepts

Every product has a strong contextual history and designer's challenge is to become aware of the contextual history of objects and as a result become aware of the signals that products emit through their shape and form [6]. Product semantics taps into the historic references of similar products looked like earlier in the timeline of their evolution, this strategy is what renders a product recognizable. Product semantics is a human-centered approach to design [7] and has evolved into a field of empirical study [6]. Essentially, it focuses on second-order understanding, which means the designer must understand how the users understands a particular product.

Designers and companies who are able to incorporate a certain meaning in product forms are able to gain a competitive advantage [5]. Meaning transmission is a central concern of the product semantic theory and it is inherently linked with language [7] this means what cannot be clearly defined in language is thus difficult to translate into Design [8]. Products are constant transmitters of meanings, and regardless of how designers use color, shape, form and texture in designing a product, messages are being constantly sent out using language structures that deal with meanings, and underpin the theory of product semantics [9]. Product Semantics is the expression of meaning through form [10].

Meanings reflect the psychological and cultural dimensions of a being human [11]. Verganti says meaning attribution is strongly linked to a person's values, beliefs, norms, traditions, emerging from an individual's cultural model. Over the course of civilization certain imagery has become deeply engrained in the collective conscience of cultures and society [6].

The term product semantics was first coined by Krippendorff and Butter in their 1984 essay, Product Semantics: Exploring the Symbolic Qualities of Form [12]. As a theory Product Semantics is focused on studying the symbolic qualities of products.

Traditionally communicating an intended meaning through product forms has been cast as a very difficult objective to achieve by design theorists [13], even though form generation is a very central concern of the product design community. Product semantics can be used to give a strong instant impression of the product's purpose or meaning [14]. In terms of product design, semantics can be applied at a low level to detail controls and features which can be manipulated or also at a high level by visualizing the very purpose of a product for a user [14].

2.2 Relevance of Meaning Communication to Product Character Theory

Products communicate meaning from adjectival constructs or visual metaphors extracted from language structures called characters. Product semantic theory leverages the use of physical metaphors to transmit the underlying functionality of a product and render it instantaneously recognizable. The HCI community defines a metaphor as the practice of using an existing mental model of a similar object and manipulating its meaning to suit a new context aiding in understanding [14]. The term *mental models* emerged in 1983 [14], essentially suggesting that external arrangements have to align with the users' internal knowledge structures. Thus product characters are cognitive structures [15]. Product semantic theory and character theory propose that based on the characters which products express, they are bearers of messages or meanings.

The appearance of a product is not just visual but includes also sound, internal mechanisms, smell and tactility [4, 16], though since this research is focused on a non-instrumental product communication, the focus is on visual sensing. Most of the information captured in a human-product interaction is through the sense of sight [8].

A character can be ascribed with as much as a casual glance [16], it is a high level description. "A character is a unity of characteristics i.e. not a simple collection, but with related characteristics integrated into a coherent whole" [16]. This means all the characteristics unite to send a common message to the user of the artefact. A characteristic in turn is a higher order attribute. An attribute communicates all the specifications of a product such as color, texture, weight, tendency etc. [16]. Product attributes are classified as either extrinsic or intrinsic [17]. Intrinsic features are physical attributes of a product [18] such as the shape, geometry, composition, proportions, color, finish, and technical performance.

Certain combinations of intrinsic features communicate certain appearance attributes in products, for example, angular, metallic-looking appliance can appear modern [5]. Though designers and users do not read the attributes of products in the same way. Krippendorff [19] says the presumption cannot be made that the way designers codify meaning in a product appearance is the same one which users pick up. Essentially experts (designers) and ordinary people (consumers) have a qualitatively different understanding of design, hence it can be argued that just as meaning, ordinary users are not able to pick up product attributes like designers as well [1, 20]. Ordinary user read fewer attributes in product appearances, thereby reading less variation. Experts can read more abstract attributes [21].

2.3 Impact of Scenario on Character Perception

Hassenzahl [15] undertook a study which questioned if product attributes could be grouped. He says that fundamentally products allow users to either manipulate their environment or express identities (symbolic value). Product attributes which support strong possibilities of utility, functionality and emphasize usability are pragmatic. Typical examples are 'clear', 'supporting', and 'useful'. A pragmatic product is instrumental in nature and fulfills a behavioral goal i.e. hammer drives a nail. Attributes which instead emphasize an individual's psychological wellbeing are classified as Hedonic i.e. relating to pleasure. Typical examples are 'impressive', 'exciting', and 'interesting'. A product is perceived as pragmatic when it provides efficient means of manipulation (hand tools) and hedonic when it provides simulation (feature loaded software), identification (social network homepage) and provokes memories (souvenir).

The usage mode of the user and the prevailing scenario while approaching a product decide which attribute group will be more appealing to him. When he is focused on completing a specific task, he expects efficiency and effectiveness. When the user is mainly focused on the act of using, the product here itself is the focus. Here high arousal is actually preferred otherwise boredom would set in.

Even though it is already difficult to align the intended attributes coded by the designer with the ones visually sensed by the user, the matter is further complicated by the motives of the user since motives can influence perception [22]. If the product is purely aesthetic in nature i.e. a painting, then the user will ignore reading appearance attributes relating to functional motives and focus on symbolic motives [1, 5, 23]. This information is relevant when undertaking any study on meaning communication through shape coding because it highlights the importance of selecting a suitable product category.

3 Box Designing Project-General Considerations

The design teaching focused on highlighting the physical properties underpinning the 3 universal product characters. The process and tools were part of the author's teaching in the National Institute of Design (NID) India and University of Madeira (Uma) Portugal. The process was structured in such a manner so that the users visually decoding the target product were able to appreciate the product 'appearance' both from functional and aesthetic (symbolic) motives. This consideration reflected through the selection of a product typology which was neither too heavily weighted towards being a pragmatic nor a hedonic product.

The product category selected was a box shape measuring 150 × 100 × 60 mm to be modelled using EPS (expanded polystyrene) foam; small enough to be perceived as a handheld product and yet big enough to give the designer enough material to manipulate easily. The size of product influences the quantity and variety of descriptive terms users utilize to describe a product, and smaller handheld products elicit more sensorial descriptions than larger appliance sized products due to the possibility of achieving a tactile interaction [24].

Since the study target was capturing product intrinsic features linked to form, shape, composition, and proportion, any considerations of color, texture and material were removed. Form is the boundary of matter by which we distinguish objects from one-another in their environment [25]. Shape refers to the external two-dimensional outline or appearance of something, determining its boundary [26]. All models developed during this study were painted white, devoid of texturing, to achieve a uniform finish, look and feel. Materials have a psychology of their own, and a user material relationship exists while attributing meaning [24].

3.1 Students

The teaching was divided into 2 phases. The first phase is based on a 2-day workshop in National Institute of Design with 20 Master level product design students (N = 20, 55% males, mean age = 27). The data captured from the first phase was validated by re-conducting the same design exercise in the University of

Madeira in a 4-week form studies classroom project consisting of 32 Bachelor level design students (N = 32, 56% males, mean age = 21).

3.2 Teaching Process-National Institute of Design (NID)

Step 1: **Theory lesson**—The workshop began by giving the design students foundational theory and basic concepts of semantic theory, character theory and Gestalt theory.

Step 2: **Product examples**—Students were shown samples of handheld products such as perfume bottles and cosmetic products. All samples had all extrinsic features such as branding removed and painted in white. Students were asked to assign them opposing characters (male-female, playful-serious, heavy-light etc.) in order to train them in applying semantic and character theory. Next the students were presented samples of computer mice modeled in white EPS foam and asked to sort them according to simple, modern, and playful. These mouse samples were picked by design experts to ensure each sample fit one of the 3 universal characters. A voting and ranking approach was used to group the mice samples into 3 characters. Mice with sharper more angular lines, chiseled faces were voted as modern. Mice with more basic geometry, containing curves coupled with straight right angled edges were voted as simple. Mice with more organic, bulbous forms, containing generously rounded radii were voted as playful.

Step 3: **Moodboards**—Based on the author's previous research [8] students were shown 3 moodboards containing product details and asked to attribute one of the 3 universal characters to them (simple, modern, playful). The character attribution was done through a voting process and each of the three moodboards were correctly identified. The moodboards were constructed by design experts in accordance with the "design led" and "expert mindset" proposed by Sanders [27]. Moodboards are visual manifestations of product characters containing images of small handheld products, electronic appliances, and household products. The moodboards used here reflected the pragmatic and hedonic attributes of the character.

Step 4: **Brainstorming**—Students as a group shortlisted brands, features, and shapes representative of each character on large posters. This step was done so that the designers can form a mental model of 'indicative parameters' for each of the 3 characters. Since brands adopt a strategic approach to forming their products, reference to them gave the designers examples of differing possibilities for detailing physical attributes underlying each character. Features which emerged for simplicity were: continuity, basic, smooth, clean, essential. Features for modern were: merging, curvy, angular, edgy, unstable, and polygonal. Features for playful were: surprise, bulgy, soft, bouncy, unpredictable, hidden, and asymmetrical.

Step 5: **Designing and modelling**—The students were split into 3 groups, each assigned one of the 3 characters. The moodboards discussed in the previous step were given to each student, indicating in text 5 synonyms and the antonym of the desired character to guide the designer strategies to follow and avoid.

Each student had to design a box measuring 150 × 100 × 60 mm, and assign an imaginary use to it. The detailing of the partition line between the lid and the base and the opening mechanism was to be shown, to avoid the risk of students forming their boxes as an abstract sculpture reducing the consistency of the final output.

The designing was a 2-step process: A line drawing on an A4 sheet showing the orthographic and isometric projections followed by foam model making.

Step 6: **Judging and voting**—For an unbiased voting procedure, the completed models were arranged on a tabletop against a white background. Only the line drawing for each model was displayed behind each model to assist design non-experts, in case they face issues reading subtle definitions and curves of the physical model.

54 participants split into four groups were invited to judge the models, all mixed male and female. First three groups consisted of design students (expert user group), mixed between animation design, ceramic design, and product design, both Bachelor and Master levels (N = 44, males = 19, mean age = 24). The fourth group consisted of staff and administration employees of NID (N = 10, mean age = 48, males = 6), with no design training (ordinary user group).

Participants judged visually (non-instrumental) in isolation assigning one of the three universal characters to each box using a secret ballot. The moodboards were prominently displayed to assist non-expert users decipher the visual manifestation of each character.

Step 7: **Qualifying successful examples**—20 models were each judged across 3 possible characters. For a model to be declared successful, a cutoff range of 50% was established, indicating a simple majority of users must agree with the intended meaning. The aim of the research was to establish physical properties which are commonly understood, representing users' general perception, and existing literature has discussed how a cut-off range of even 40% excludes idiosyncratic examples [4, 5].

3.3 Output-Extracted Physical Properties

Special attention was paid to the difference in voting patterns between the expert and ordinary user groups.

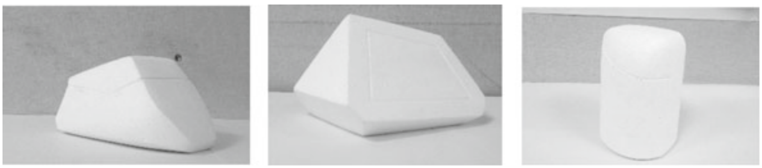
Figure 1 shows successful ‘simple’ boxes. Model 1 was read correctly by both the expert and ordinary user group (72% overall success). Although the majority in student expert groups judged correctly, the ordinary user group was somewhat undecided (40% success) in reading model 4 (57% overall success). They both have straight sides with uninterrupted basic forms, appearing symmetric. The straight sides are of-ten interrupted by with curving edges. Simple forms can contain sides which are sloping (drafted) though flat and lacking undulations or sudden variations. Model 17 was least successful, read as ‘playful’ by all the user groups (15% overall success). It was attributed with large flowing curves, big radii around edges and extremities and convex shaped edges.

Figure 2 shows successful examples of ‘modern’ boxes (81 and 80% overall success). Models 15 and 18 were read as strongly modern by in the expert user groups though not so by the ordinary user group which remained undecided (30 and 40% success). They possess angular lines and sharp edges, with sudden changes in the shape geometry, giving them a somewhat unstable and asymmetrical appearance. Model 2 was the least successful (37% overall success), instead read as ‘simple’ by almost 50% of the users. Model 2 shares attributes with successful simple’ models—straight sides, interrupted by curved edges, with a symmetric form.

Figure 3 shows successful ‘playful’ boxes. Models no. 8 and 19 (80 and 81% overall success) were read as strongly ‘playful’ by the expert user groups, while the ordinary user group rejected them (30 and 20% success). Notice the similarities between these two models and model no. 17 which was also voted as strongly

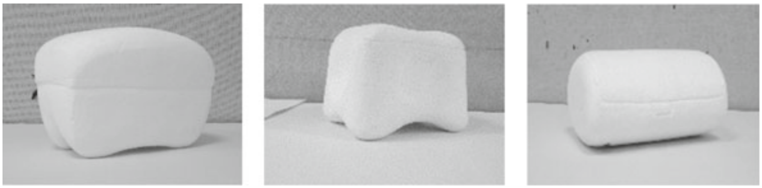
Model no.1 Model no. 4 Model no. 17

Fig. 1 *Simple boxes:* model no. 1 and model no. 4 most successful, model no. 17 least successful and read as playful



Model no. 15 Model no. 18 Model no. 2

Fig. 2 *Modern boxes:* model no. 15 and model no. 18 most successful, model no. 2 least successful and read as simple



Model no. 8 Model no. 19 Model no. 6

Fig. 3 *Playful boxes:* model no. 19 and model no. 8 most successful, model no. 6 least successful and read as simple

playful by all the user groups. These forms contain large bulging geometries, generous radii around corners and gradual variations in the surfaces, expressing mostly convex sides. Model 6 (35% overall success) was read as simple by both the expert and ordinary user groups due to its similarities with the models in Fig. 1.

4 Teaching Process-University of Madeira (UMa)

Except for a few steps, the teaching process followed here was similar to the previous one (Table 1). This process was part of the university regular semester teaching, so the timeline was extended to a month. The students were Bachelor first year hence quite novice compared to the Master level NID students necessitating a few alterations.

Reasons for omitting or altering certain steps are briefly discussed below:

Product examples—In UMa this process was embedded in a semester level drawing and modelling lab subject, the teaching aim was giving the novice designers drawing and modeling skills, with an additional focus on ability to manipulate physical properties of forms to develop shape coding skills. Thus the step on product examples was less elaborate although the students were asked to read shapes of models from different product categories and classify them into the 3 characters.

Table 1 Teaching process steps followed in NID and UMa

Teaching process	
NID-India	UMa-Portugal
1. Theory lesson	1. Theory lesson
2. Product examples	2. Product examples
3. Moodboards	3. Moodboards
4. Brainstorming	4. Brainstorming
5. Designing and modelling	5. Designing and modelling
6. Judging and voting	6. Judging and voting
7. Qualifying examples	

Brainstorming—Instead of focusing on brands, studio discussing was more theoretical, directed at extracting adjectives (expressive words) which are synonymous to the 3 target adjectives and intrinsic features (shapes, geometry, proportions, details) which express the physical properties.

Qualifying examples: Since the judging and voting was performed in the classroom following a group voting and free association technique, there was no follow-up step was necessary to separately qualify the successful examples. The author performed the free association based on the students' inputs to maintaining a non-instrumental, visual-only judgement criterion for them. Models which could not be associated with any of the 3 characters through group voting were discarded from the study.

4.1 Output-Extracted Physical Properties

Figure 4 shows boxes judged 'simple', reflecting straight lines and basic geometries. The edges and corners are filleted, the surfaces are continuous with no sudden changes. A clear communication of functionality is emphasized. Figure 5 shows 'modern' boxes, which much like the previous workshop exhibit sharp angular

Fig. 4 Simple boxes

Fig. 5 Modern boxes

Fig. 6 Playful boxes

sides and asymmetrical compositions. Continuous plain sides interrupted randomly by deep long fissures/slits were also recurring. Figure 6 shows 'playful' boxes. These boxes exhibit curved shapes, convex surface geometry, the edges are generously filleted with no hints of sharp angular lines. As this was a moodboard and visual research driven project, the emergence of animal forms is interesting here, probably reflecting the industry trend of playful household products in Europe. The overall results of the 3 characters though confirm with the NID output.

5 Final Discussion and Conclusion

This research investigated the physical properties of the product characters- *simple, modern,* and *playful*, claimed to be universal in their communication within existing design literature. This research should be seen as an addition to existing literature into shape coding strategies of product characters. Benchmarking the physical properties extracted here make the universal product characters more *objectifiable* to designers [1]. This study investigated two questions: (1) if the same set of intrinsic features (physical properties) are consistently attributed by designers across different cultural paradigms to construct a specific product character. (2) If both expert users and ordinary users read these physical properties in a consistent manner, correctly identifying the intended product character.

Regarding consistent attribution of physical properties, this study extracted a range of intrinsic features which were replicated by designers, with varying levels of design expertise, from India and Portugal. The author continues to test the attribution of these characters in diverse handheld product categories, further substantiating the *generalisability* of these physical properties. Figure 7 illustrates the attribution of simplicity and playfulness in a semester design project of 3d printed tape dispensers. The physical properties are similar to the box models. These intrinsic features can offer guidance to designers wishing to attribute these

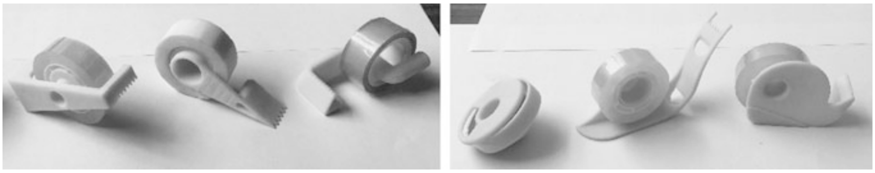


Fig. 7 'Simple' (*left*) tape dispensers with geometric shapes and basic forms, 'Playful' (*right*) tape dispensers with animal forms and humorous intentions

characters across different handheld products opening doors to further investigations. Finally, this research has made a contribution to existing literature in the issue of helping designers acquire application skills of theoretical tools and product semantic theory while working with meaning communication in product design [28].

5.1 Further Investigation and Future Development

Even though the expert users correctly identified the product characters in a blind evaluation setting thus validating the physical properties of each of these product characters, the ordinary users remained undecided by not voting decisively. A reason for this anomaly could be that the box shapes appeared more abstract to the ordinary users, where they could not quite attach a pragmatic use to these objects thus had difficulty in reading them. Perhaps ordinary users evaluate product forms with a different mental state than designers (goal vs. action mode).

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Nature Inspired Design—A Review from an Industrial Design Perspective

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Abstract The paper, an ongoing doctoral research, makes an inquiry into nature inspired design from an industrial design perspective. The study examines various systematic methods developed by researchers and finds that they are strongly function oriented while methods adopted by industrial designers are based on observation of natural systems for nature inspired design. Literature review indicates that researchers and designers work under different environments and constraints, and further finds that the approach taken by designers face criticism as well as support to their methods. This paper highlights that existing researches are dominantly focused on functional aspects while aspects that deals with the form are not sufficiently explored for nature inspired products. It also suggests the importance for the design community to extrapolate methods that are based on design science principles in seeking creative solutions for nature inspired products.

Keywords Nature inspired design · Biomimicry · Industrial/product design · Product aesthetics · Product form

1 Introduction

This paper will attempt to examine the systematic methods undertaken by researchers and the methods followed by industrial designers for nature inspired design. Systematic design methods follow the scientific approach which is more function oriented. It attempts to understand the principle behind occurrence in a natural phenomenon. On the other hand designers have to deal with the creation of products that involve both function as well as aesthetics in the conceptualization of the product form. With a focus on the creation and generation of product form,

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based on intuition, designers are often criticized by scientists and engineers for being 'non-scientific' in their approach, since the process is not verifiable. A closer and in-depth analysis is required in order to understand if the creative task of form generation can be subject to a verifiable rigor following a design science approach and made explicit.

In the following sections terms, methods and approaches adopted by the scientists, engineers and designers will be discussed, followed by their limitations, criticisms of designers approach and the few studies that will not only defend such criticism, but will provide a new vision to work in the less explored areas of the forms and emotion of nature inspired products.

2 Review of Terms, Systematic Methods and Tools for Nature Inspired Design

Taking inspiration from nature is a very innovative, creative and novel approach to design products. Human-beings are seen to be practicing it since Stone Age. One can cite a number of innovations inspired by nature—caveman made weapons by observing teeth of carnivores and the Chinese invented artificial silk 3000 years ago. In 1488 Leonardo da Vinci designed a flying machine inspired from the wings of bats. Wright brothers in 1903, made the first successful airplane inspired by large birds and Velcro invented by George de Mestral in 1948 was inspired by the burrs.

Over time, the study of nature inspired innovation has led to new definition of terms. In 1960, the term 'Bionic' was coined by Jack E. Steele as the science of constructing systems with some functions copied from nature [1, 2]. Today Bionics has been applied in replicating real organs in the design of medical prostheses. In 1969 Otto Schmitt introduced the term 'Biomimetic' as the study of biological mechanisms, structures and materials to produce products artificially [1, 2]. In 1997 Janine Benyus in her book 'Biomimicry: Innovation inspired by nature' popularized the term 'Biomimicry' as "new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems" [3]. "Biologically inspired design is the use of designs found in nature for analogy and inspiration in designing technological systems" [4]. Even in art, the term 'Biomorphism' refers to an art movement having its roots associated with Surrealism and Art Nouveau. The word 'biomorphic' is commonly used for abstract, free form and organic shapes used in arts and design [5]. Painters, poets and musicians seem to be inspired from nature for their art. Scientist, engineers and industrial designers too, take their inspiration from nature. Luigi Colani is famous for his 'biodynamic forms' and Ross Lovegrove is known for his 'organic design'. Both seem to draw inspiration for design from nature. Terms may be different, but broadly they have a common focus of being 'Inspired by Nature'.

Systematic methods follow two broad approaches in nature inspired design (Table 1). In the first approach, the researchers start from a problem statement and

Table 1 Systematic methods for nature inspired design

First approach	Second approach
Top-down process [6]	Bottom-up process [6]
Problem-driven biologically inspired design process [7]	Solution-driven biologically inspired design process [7]
Biomimetic by analogy [8]	Biomimetic by induction [8]
Challenge to biology [9]	Biology to design [9]

tend to search for relevant biological analogy to get a solution. In the second approach researchers have a biological phenomenon in their mind and that leads them to search for its application in the man-made world [6–9].

In addition to the above broad approaches, there are specific methods like—BioGen, a methodology for biomimetic design concept generation developed to solve problems of architecture, but can be used by other disciplines other than architecture [10]. Junior et al. proposed a methodology based on bionics research to design new products [11]. Product Design from Nature (PDN) methodology is an integration of three approaches viz. reverse engineering, 3D geometrical computation and inspiration from a designers sketch of biological system [12]. Lenau [13] in a study explored the successful use of biomimetic design methodology for engineering design. Researchers from different scientific fields developed these approaches. They outlined the methods in general terms to make them suitable for end users with varied educational backgrounds.

Biomimetic involves the transfer of information from the biological domain to other domains like engineering, material science, etc. Many computational tools and databases have been developed to make easy retrieval of this biological information and help designers in ideation phase [14–17]. Some of the tools developed include:

- IDEA-INSPIRE is a computational tool based on SAPPhIRE model of causality. The biological and engineering analogies can be retrieved from the database based on the description of problem in terms of constructs of SAPPhIRE model [18].
- Design by Analogy to Nature Engine (DANE) is based on the Structure Behavior Function (SBF) model. It helps user to understand the SBF relationship between biological system and engineering system. The user can construct new SBF model and can add it to the library [19].
- 'Ask nature' is a database based on biomimicry taxonomy that allows user to search information on biological phenomena and biomimetic products [20].

Modified biological information and keeping the database up-to-date manually are few disadvantages of these databases [21]. Ideation in biomimetic is a knowledge based ideation which demands large repository of biological knowledge for creative thinking and should always stay updated. Vandevenne et al. [22] employed scalable web crawling approach to continuously develop and update the database based on biological strategies. 'Biologue' is an online citation cataloging system based on the concept of social semantic web that helps in building the database and keeping it up-to-date [23]. ‘BIOscrabble’ uses PubMed, which is a meta-database, allowing users to search large updated biological research articles [14, 17, 21].

Paper based and computer aided catalogues were also developed that contains biological principles and corresponding technical functions. Researchers have also developed certain engineering to biology translation tools to link engineering and biological terminologies [14, 17]. BioTRIZ was developed on the basis of inventive principles of TRIZ. It is based on the analysis of 500 biological phenomena with 270 functions forming 2500 contradictions. Unlike TRIZ having 39 by 39 contradiction matrix, BioTRIZ uses 6 by 6 contradiction matrix [1]. Considering the drawbacks in terms of cost and availability of these tools, the biomimicry card deck was developed for novice designers that helps them to enlarge the solution space for solving problem through biomimicry [24]. Biomimicry Innovation Tool (BIT) uses the idea of Problem Based Learning (PBL) Method, innovation and biomimicry to solve technical ergonomics design problems [25]. There are Nature Inspired Design (NID) strategies which include Biomimicry, Cradle to Cradle, Ecodesign and Natural Capitalism to apply principles of nature in a holistic way focusing on the system rather than developing a product [26, 27].

3 Limitations of Systematic Methods

Although systematic methods are useful for designers and engineers, they have certain limitations too. It is identified by researchers in their studies that there are learnability issues of these tools among professional designers and design students. Fu et al. [15] in their study found that learning to use these tools/methods is different from conventional design methods and tends to increase the cognitive load on designers. A study by Glier et al. [16] indicate that it is difficult to train students in this field because biomimetic is still in developing phase and is not included in the academic curriculum. Hsiao et al. during their research found that the existing tools and methodologies are insufficient to train students in organic form transformation and abstract associative thinking [28]. Researches also indicate the reasons why designers and industries do not use these methods to design their products commercially. In the comparative analysis of five bio-inspired design methods by Carlos et al. it was found that the methods failed to deliver a communication effective product [29]. Jorgensen et al. [30] found that current methods deal with only functionality and not aesthetics of a designed product, which later became the base for the development of their design methodology focused on aesthetics. Kennedy [31], through a case study in his research explains that current methods and tools are focused on generating concepts and are insufficient in transforming concepts into the implementable solutions. Fu et al. [15] identified that most of the tools/methods are part of academic projects and are not easily accessible to designers. A study by Volstad et al. indicate that the tools are still in developing phase, which makes it difficult to predict their usability and are too costly for small design studios to afford [24].

4 Designer's Approach to Nature Inspired Design

Focusing on form and aesthetics of a product, designers have developed their own methods. Visual interaction is the first interaction of a user with a product and this could be one of the reasons why designers emphasize more on product form. To bring novelty into the product form, designers often take inspiration from nature. The designer's approach to design nature inspired products focusing on styling and aesthetics starts with visual thinking. The design guidelines for training industrial designer to take inspiration from nature are not well documented in the available literature since it is more application based rather than research based. Few researchers have mentioned about designers approach, which starts with observation of natural systems to identify form elements. Wen et al. [12] describe 'Art and Design method' in which a designer observes a natural object to identify form elements and creates a conceptual design in the form of 2D sketch which can be scanned and used further to produce CAD models. Hsiao et al. outline a proposal in which the process of transforming an organism form into a product form involves a concept transformation stage, which is further divided into two sub stages viz. utilizing the concept of product semantics and morphology analysis. The author developed a Diagram for Biomimetic Product Design (DBPD), which guide students in observing, extracting and transforming the biological features of natural objects [28]. 'Applied aesthetics in biomimetic design—a guide', is a work of Technical University of Denmark (DTU), which proposes seven methods that can be used individually or complement each other in taking inspiration from nature's aesthetic attributes in a methodical way [30]. The study by Huang et al. employes a method in which students first identify the objective pattern in nature which are responsible for aesthetic experience. After analyzing these aesthetic patterns, 2D and 3D compositions are developed based on aesthetic principles like unity, harmony, proportions, balance, rhythm, symmetry, repetition etc. [32].

5 Limitations of Designer's Methods

For industrial designers, dealing with complexities of natural forms, their manufacturability and at the same time satisfying the customer's psychological needs always remained a great challenge. Due to the complexities of natural forms designers often face a problem in analyzing and extracting the design elements for product form [28]. Designers approach in designing product form are more often based on experience and intuition. It therefore makes it difficult to design a product that exactly meets customer psychological needs [33–35]. According to

Kamehkhosh et al. “designers usually reduce complex forms to their basic geometries and proportions, in order to find orders in their complexity and to harmonize them with their design paradigms…”. They believe that this common vision to nature “…deprive us from perceiving its reality” [36]. Maintaining a balance between natural form and abstractive form is a challenge for both novice as well as professional designers. Literature suggests that the degree of abstraction of a bios form is an important factor in consumer pleasure. It is found that less abstractive bios form have a higher pleasure response than those with more abstractive form [37].

6 Criticism of Designer’s Methods

Success stories of products like Juicy Salif lemon squeezer, Volkswagen Beetle, Diatom chair, TY NANT water bottle shows that the psychological aspects behind product aesthetics and its effect on product usability can’t be ignored. The importance of product aesthetics is evident from the literature of emotional and pleasurable product design in the above examples and show that the industrial designers have to deal with both function and aesthetics of a product. However, designers continue to face criticism on their approach being focused mainly on product form and aesthetics [10, 38, 39].

The researchers who work under different environments and constraints following a systematic method focused on function, argue that—“Imitating or being inspired by natural-looking forms, textures and colors alone is not biomimetics; it has to have some biology in it. This means that to be truly biomimetic, a design should in some way be informed by nature’s science, not just its look” [38].

It is an argument that the design community should reflect upon.

7 Researches/Studies that Support Designer’s Methods

There are also case examples that are in favor of the designer’s methods that counter the above criticism. Edward O. Wilson [40] in his book ‘Biophilia’ argues that there is a bond between humans and nature. He defines Biophilia as “The innate tendency to focus on life and lifelike processes”. Many researches have reported the positive effects of natural environment and its features on human health and psychological comfort [41–44]. The biophilic design is an application of biophilia concept in built environments. Biophilic design uses the natural elements as the design inspiration in built environment [45]. Nature is a rich source of analogies and metaphors. Designers use metaphors in their designs to make products more communicative and expressive both functionally as well as aesthetically [46]. Exposure to biological examples during design process helps in increasing the novelty and variety of ideas generated [47]. Natural forms have always been a source of inspiration in developing new products by industrial designers [48]. Products with bios form evoke higher intensity of consumer pleasure and emotional responses than those without bios form [37, 49]. Automotive industries, encourage the use of animal form for styling because of optimized mechanical performance and wide appeal of the vehicle [50]. Understanding the semantic and emotional responses related to animal inspiration can help designers develop highly expressive design solutions [51].

All these studies explain the importance of nature in industrial design and supports the designers approach in designing creative products inspired by nature.

8 Conclusion

This paper has examined systematic methods undertaken by researchers and the methods followed by industrial designers for nature inspired design. The results of the review indicate the importance of both systematic methods and designer's method from an industrial design perspective. Systematic methods are necessary as they help to increase the overall number of ideas generated and products produced by such methods are more sustainable than the products available in markets. On the other hand designer's methods are necessary to design products which are more communicative and expressive both functionally as well as aesthetically. The review support the conclusion that the existing research is more focused on functional aspects and the area which deals with the form and emotion is not sufficiently explored for nature inspired products from industrial design perspective.

9 Discussion

The true nature inspired design is all about the abstraction of the principles in nature. It could be the abstraction of a functional principle or the abstraction of a natural form to evoke certain emotions, but both kinds of abstraction require the understanding of the underlying principle existing in nature. It is evident from the available literature that the principles in nature are understood only in terms of functionality and areas which deals with the form and emotions are still left unexplored with the exception of a few studies [37, 51, 52]. It is expected that the future research based on design science principles in seeking creative solutions for nature inspired products and product forms may lead to a new research domain of '**Nature Inspired Design Science**'. Nature is a great source of inspiration for both form and function. For an industrial designer it is very important to extract the underlying principles for both, form as well as function as per the demand of the project.

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Design as Culture: Understanding Vernacular Architecture of Indigenous Tribal Community of India

Harshitha G. Raju

Abstract This paper presents understanding of symbolic meanings in vernacular architecture of a tribal community in Karnataka, South India known as *Jenu Kurubas*. An ethnographic study is conducted to document the lifestyle, beliefs, narratives and customs of the community. Further, structural semiotics is applied to analyze the myths and narratives to identify the hidden messages through oppositions and correlations. The study concludes that the oppositions, logical relations and correlations observed in narratives are also represented in the geographical, socio-cultural, cosmological and techno-economic schemas as principles and attributes of vernacular architecture.

Keywords Vernacular architecture · Structural semiotics · Myths · narratives · Ethnography · Tribal community

1 Introduction

As human beings, we are unique from rest of the species due to the capability to design and be part of culture. Culture within a community is reflected through design and likewise design is used as one of the means to portray culture. The term 'design' here refers to spatial design at different scales from that of a whole settlement to interior architecture of a community. Oliver [1] defines culture as the totality of values, activities and products, including buildings of a society, which give meaning and direction to the lives of its individual members that are learned and not transmitted genetically. Likewise, as culture is distinct to a place and its people, so is vernacular architecture; contextual, culture specific, region specific and rooted to a locale. Rapoport [2] is of the opinion that vernacular architecture is the

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result of direct and unconscious translation of culture into physical form. He also states that the design decisions in dwellings and settlement plans may be severely limited due to culture of the society [3]. Glassie claims that the study of vernacular produces knowledge that all architecture is cultural, and that all cultures differ in structuring their hierarchy of values [4].

But the aspects of culture may not be directly depicted; they are ingrained to a greater extent than what they appear to be. Vernacular buildings are elusive with symbolic meanings which may be spiritual, cosmic and anthropomorphic or of other significance, reflecting the customs and beliefs to satisfy the psycho-social, as well as the physical needs of the inhabitants [5]. Culture is described as a semiotic system, an ensemble of "structures of signification" that act as an external control system for human action [6]. Dubos regarding human behavior writes that man symbolizes everything that happens to him and then reacts to the symbols as if they are actual environmental stimuli [7]. Mumford claims that man attained specialization in the realm of culture through myths and rituals even before material and technological aspects of nature [8].

However, the symbolic and connotative meanings in vernacular architecture are impossible to be deciphered without the knowledge of the cultural past of the land and people. Thus, an insight into the customs and rituals, social and economic status, and especially 'myths and narratives' that are passed on from generation to generations are a means to realize the hidden meanings. As myths not only give understanding of history of culture, but also provide a basis for law and morality to people and answer very basic questions of life [9]. Glassie argues that narratives are embedded universally among all humans and that they are used as a means of architectural diffusion [10]. Hence, the different aspects of culture, both tangible and intangible are interlinked in such a manner that study of one provides understanding into others.

Accordingly, the aim of this paper is to realize the symbolic thought behind design decisions in vernacular architecture through analysis of myths and narratives and understanding of lifestyle, beliefs and customs of people in a community. The objectives are to explore the underlying 'deep structural system' that is obscure due to 'surface phenomena' in narratives; to refine precise knowledge about cultural influences on vernacular architecture and to understand the interaction of people with spaces and house forms.

Even though human brain is developed among all the *Homo sapiens* to the same extent they are influenced by cultural training for those living in technologically advanced society [11]. Thus the people under study chosen are *Jenu Kurubas* who are an indigenous tribal community of Dravidian origin residing in Kakanakote, Mysore district of Karnataka in South India. They live in thick forested area, technologically unsophisticated, have kept oral transmission of narratives still alive and have the same thought process as their ancestors. And also, the climatic zone in which they are located is moderate, which negotiates the possibility of climate as a determining factor for their resultant built forms and supports the study of cultural influence on their vernacular architecture.

2 Methodology

The study conducted can be categorized under two sections. Firstly, Ethnography as a qualitative approach to data collection and secondly, Structural semiotics as a method of analysis. The ethnographic study was conducted for a period of two weeks, by author physically being present with the villagers from morning till evening. During which, the information collected was through measure drawing, participant observation, interviews, photographic documentation, maintaining regular field work notes and personal documents. The people interviewed were around 20 numbers including the tribal head, subordinates, their family members, priest, mahouts (which is also a common occupation among them), elderly, residents and youngsters of the village.

Structural semiotics, which is an established method used in Linguistics was applied for analysis as Levi-Strauss too ascertains that as language and culture are both built of oppositions and logical relations; language can be used a conceptual model in analyzing other aspects of culture [12]. The phases of analysis included:

1. A detailed study of object category, i.e. vernacular architecture of Jenu Kurubas by creating a catalog of characteristic traits of their architecture.
2. Analysis of the relationships between ‘basic traits of architecture’ and ‘cultural traits of the society’ to identify the genre.
3. A concept of system by elucidating through analogy and developing cognitive patterns through deductive reasoning.

The resultant matrix obtained is one of the possibilities of several permutations as a result of objective interpretation that helped in identifying the motifs and hidden meanings through logical correlations. Simultaneously, the results obtained were validated through triangulation by verifying with their belief system, customs, rituals and their lifestyle.

3 An Ethnographic Study of Jenu Kurubas

3.1 Settlement Pattern and Design of Dwellings

The settlement of *Jenu Kurubas* known as ‘*Balle haadi’* within Kakanakote reserve forest is protected by natural boundaries with Western Ghats on to South and Kabini River to the North and North-West. The development of the settlement is scattered with few houses clustered or independent with fenced boundaries. As they do not have sub-castes, all are treated equally and have access to whole village.

The site selection for construction of house is done by placing three medium sized stones or by nailing a peg on site for three days and later checking if they have remained in same positions as a good omen for construction. The dwellings are single-storeyed, with hipped roof and are *kutcha* houses. The plan is rectangular with dimensions ranging between 3.0×4.5 and 4.5×7.5 m. They have a single

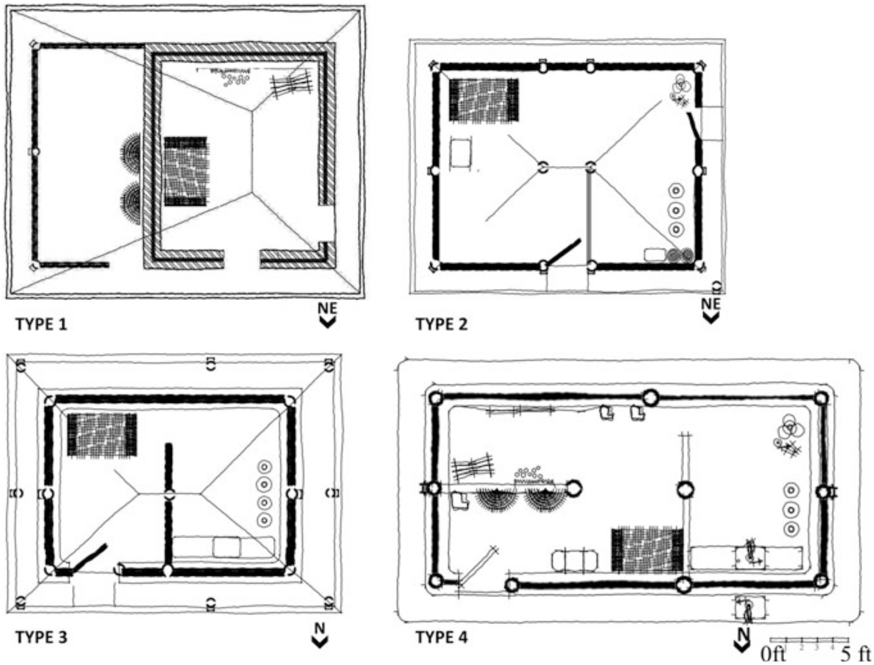

Fig. 1 Typologies of houses among Jenu Kurubas at Balle Haadi, Kakanakote

entrance, without any opening other than space left between meeting of walls and roof members. The extended plinth serves as an outdoor seating and cooking and sleeping area. The interiors basically have two spaces i.e. the living and kitchen.

The basic materials of construction used are wood, bamboo, mud and hay. The columns and beams are made of wood, while bamboo is used for walls, partitions and roofing. A thick layer of mud, both internal and external is plastered on the wall of about 0.3 m thickness and is plastered with cow-dung (Fig. 1).

3.2 Family Structure, Life-Style and Customs

The *Jenu Kurubas* follow a nuclear family structure, but their dwellings are closely located to other family members and relatives. They follow a patriarchal system. Both men and women are equally audacious, as even women go to forest almost every day to collect firewood and Non-Timber Forest Products and also work as laborers in coffee plantations. Annually all men involve in honey gathering which is a social occupation collectively done among them. The social conduct and co-operation among the villagers, family members and with their surrounding environment is affected by their beliefs and customs. They do not do idol worship or have shrines to pray as they consider nature itself sacred. They respect their ancestors as protectors of their lives thus worship their birth annually. According to their belief, there exists three worlds one above the other; the earthly, spiritual and the heavenly world.

3.3 Birth, Marriage and Death

The concept of pollution related to maturity, pregnancy and birth is prevalent and strongly followed among *Jenu Kurubas*. Every newly married couple constructs their own new house by themselves with some help from relatives within a time span of about three days. While the groom gets the necessary materials and does the framework, woman takes up the responsibility of plastering mud and finishing it with cow dung. Likewise, when a person expires in a family the complete house is brought down and relocated, or in some cases they symbolically evacuate a portion.

4 Structural Semiotic Analysis of Narratives

The oral narratives presented here are translated from a book on *Jenu Kurubas* written by Prof. Kikkeri Narayan who has been researching on them for more than thirty years [13]. They are analyzed and positioned under different motifs based on the oppositions and correlations present in the narrative which help in deciphering messages and signs.

4.1 The Myth of Origin

This myth is composed of dichotomy such as Land-Water, Single- Couple, Man-Woman, Drown- Float etc., which when logically related acquires meaning. The significance given to land, water and earth by the people can be realized through this myth. It also overcomes the belief in autochthonous birth and administers birth by two people of opposite gender and thereby existence of life (Fig. 2).

4.2 *The* 'Aalukoogo' *Bird*

The narrative speaks of events that happen both in their village as well as the forest which refers to their reverence to culture and nature. The feelings of love and hatred are also expressed among marital and kinship relationships (Fig. 3).

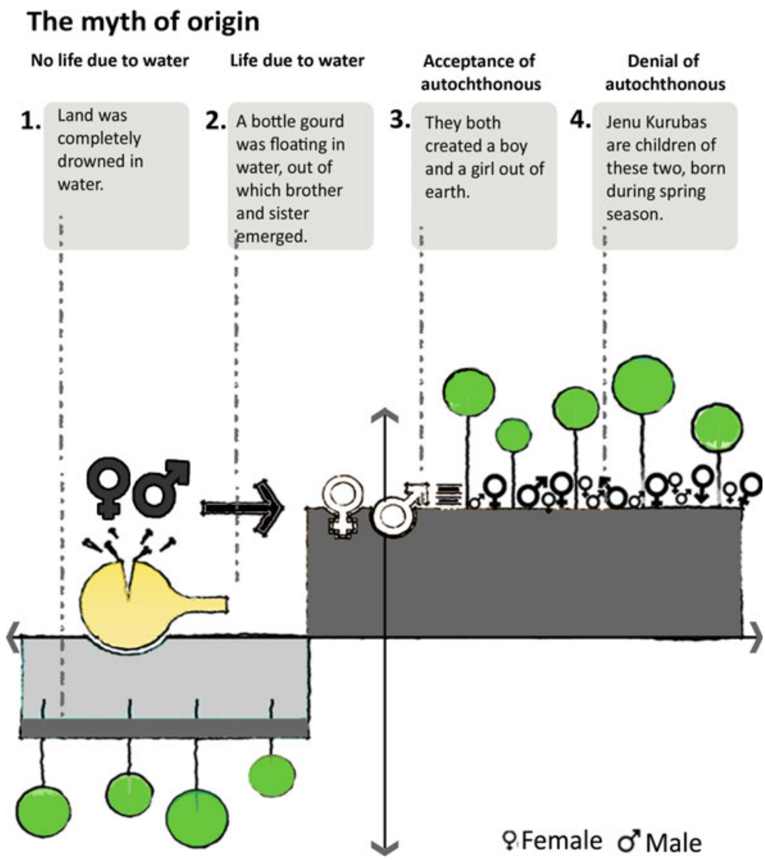

Fig. 2 Analysis of the myth of origin

4.3 Jenu Kurubas Epic Poem: Tangi

This narrative initially expresses love, sacred feelings and concern among kinship relations, thus the feature of the first column is *Sacred*. In this column a strong bond is observed between the brother and sister relationship. The second column has its feature as *Chaste,* as the young sister who attains puberty is pure both mentally and physically. The third column is about the *unchaste* act that the brother-in-law conducts with the young woman. The fourth feature is *Profane,* as the brothers kill their only sister in turn the sister curses the death of all her brothers (Fig. 4).

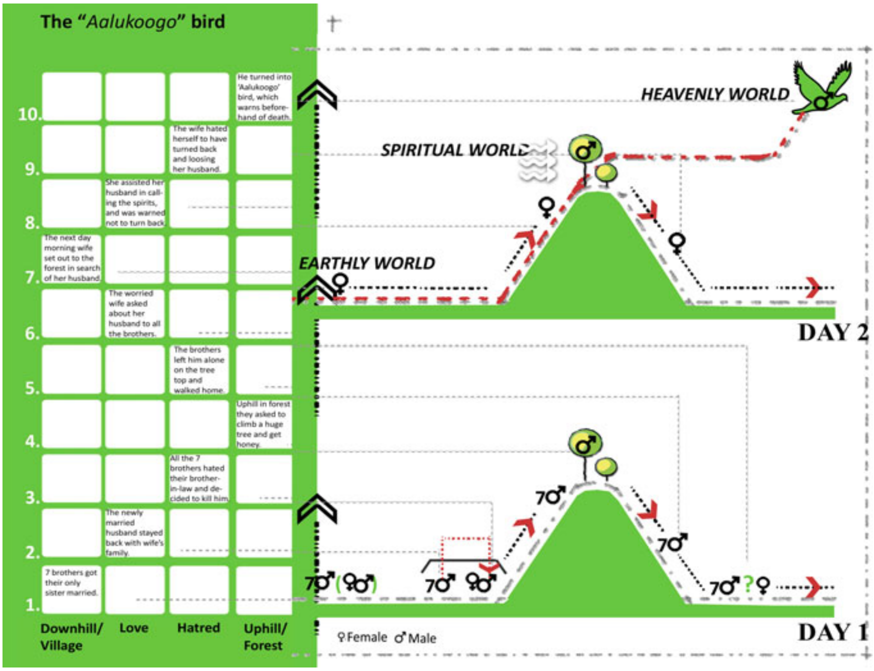

Fig. 3 Analysis of the narrative the 'Aalukoogo' bird

4.4 The Two Brothers Story

This narrative proceed with mention of oppositional pairs in the consecutive 'mythemes'. The story starts with one village and ends in other, with a disastrous beginning and a prosperous conclusion. It can be realized from the story that the chief motifs that affect the society's equilibrium as nature, kinship relations, love, death and survival and spirits in the wind (Fig. 5).

4.5 The Mouse Story

This story is a metaphor of life style of Jenu Kurubas and Coorg estate owners. The Jenu Kurubas who are like white mouse signify innocence, simplicity and down to earth behavior; whereas the description of bandicoot's luxury resembles the Coorg estate owners for whom Jenu Kurubas work as laborers in their plantations (Fig. 6).

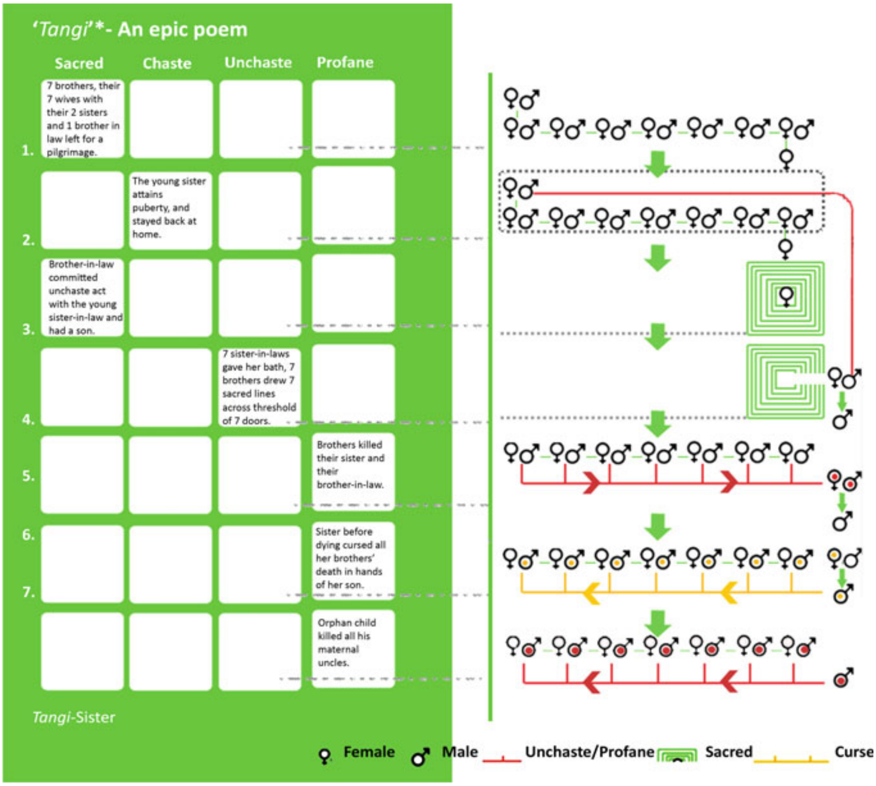

Fig. 4 Analysis of poem 'Tangi'

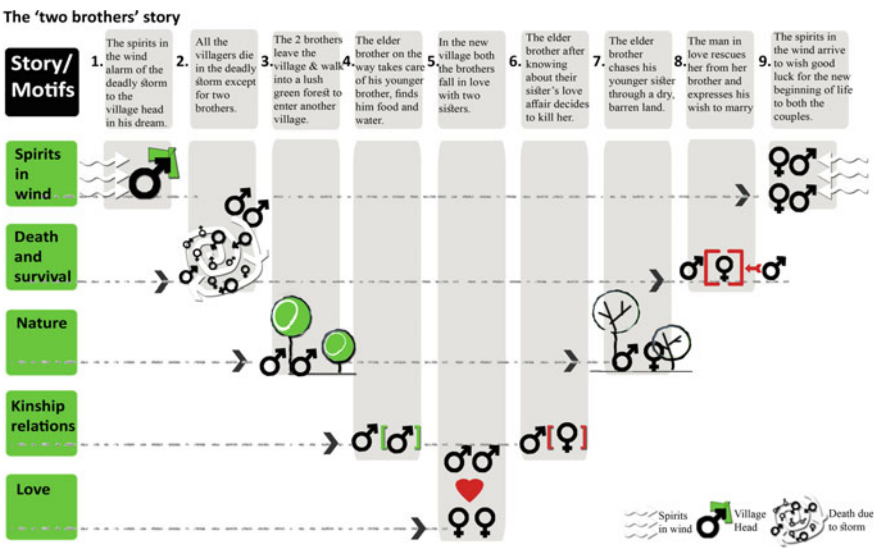

Fig. 5 Analysis of 'The two brothers' story'

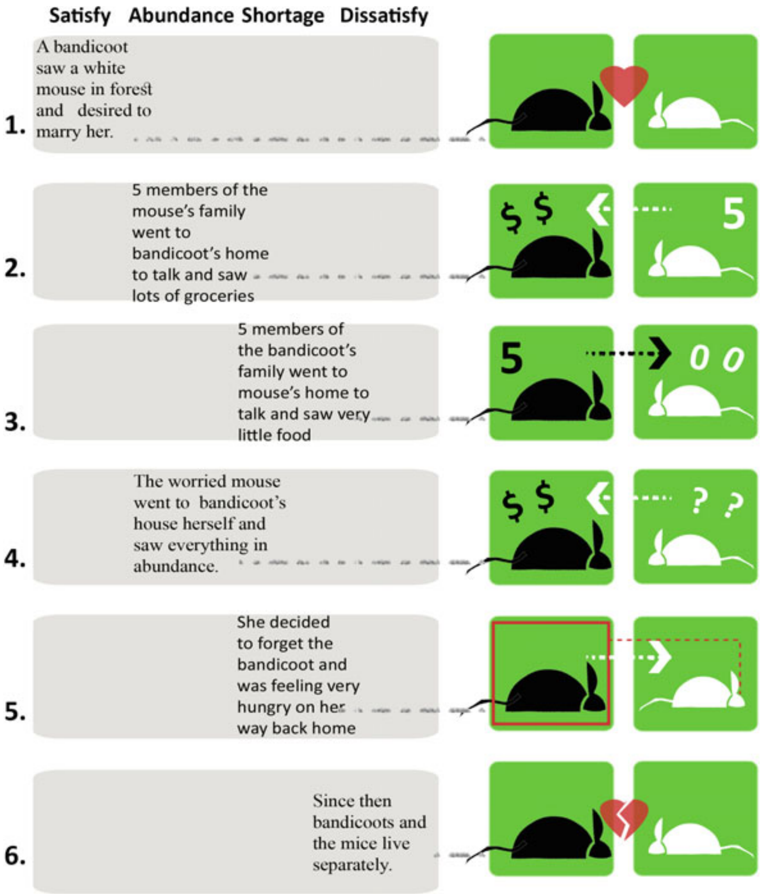

Fig. 6 Analysis of the mouse story

5 Discussion

The symbolic nature of vernacular architecture is the tangible and physical expression that represents the cultural influence of community. These influences that are transferred can be further studied under geographic, cosmological and socio-cultural schemas as presented here.

5.1 Geographic Schema

As in the epic poem 'Tangi' which gives a description of the threshold, the aspect of 'territoriality' is strong among Jenu Kurubas and can be identified at several levels. This concept is reflected through use of spaces, the notion of security and privacy. The village has benchmarks around to mark the territory through a ritual conducted by the village

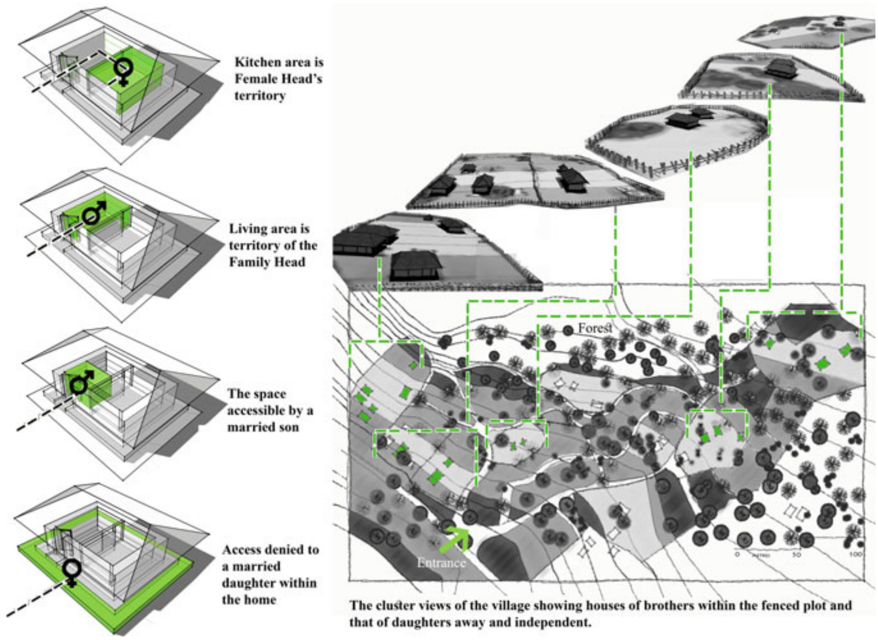

Fig. 7 Graphical representation showing the boundaries of access permitted to the family members in a house

priest to prevent the evil spirits from entering the settlement. At the cluster level, the houses are fenced, that act as physical barriers from strangers and wild animals.

Within the houses the family members follow certain restrictions, the spaces are defined that can be accessed by the male and female members. While the kitchen area is accessed only by women, the living area is territory of the male head of the family. Likewise, a married son can enter only a part of the living area, whereas a married daughter has no access at all and can use only the outdoor spaces (Fig. 7).

Also, in the narratives, there are several instances while strong bonding is observed between blood related brothers, while that with married sisters is of hatred. This is translated in their settlement patterns by having rules of positioning houses of brothers in a family within the same plot, whereas that of sisters independent and individual.

5.2 *Cosmological Schema*

The cosmological schema observes the notion of universe and its elements that are present in the minds of the people at different scales of space usage and activities. As in the 'two brothers story' the supernatural powers both good and evil traverse through wind. Likewise, *Jenu Kurubas* believe in three worlds that exist; the earthly in which they live, the spiritual which is just above their heads and consists of evil

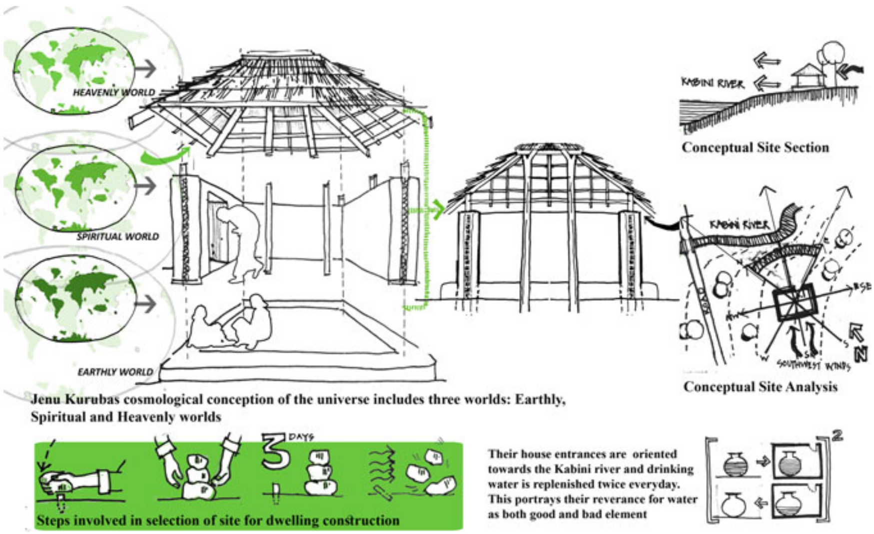

Fig. 8 Graphical representation showing an exploded view and section of a dwelling in relation to the belief of three worlds that exists among *Jenu Kurubas*

unsatisfied spirit and above which the heavenly world where godly ancestors reside. These thoughts in relation to their dwellings can be observed in design of their dwellings. The super-structure has only a small entrance without any other openings which possibly represents symbolically the fear they have towards evil spirits.

Accordingly, the plan of their houses are rectangular, and only rituals related godly spirits are done by drawing a circle to which only the priest has access. This aspect reflects their belief that shelters for humans can have corners for cosmic orientation.

The dilemma of water which is observed as an element of creator as well as destroyer in the myth of origin has implications on the orientation of their houses. They orient their houses towards to show reverence they have for water and it is also observed that due to flooding of the river Kabini or heavy rains damages their dwellings. Likewise, the water that is brought by women of the house during daytime should be utilized by evening hours and the remaining spilt away and filled again for usage till the next day morning. The belief in their minds according to one of the informants is: “Water gets polluted when kept for long hours; spirits in the wind might contaminate the water; we ought to change it twice a day.” Thus, storage of water in their houses has a limitation (Fig. 8).

5.3 Socio-Cultural Schema

The Socio-Cultural schema includes the aspects of family structure and bonding between members, hierarchy among them, kinship and marital relations, and position of women in the society. It is also seen that marriage and death are seen as oppositions, as in the ‘two brothers’ story’, in which the narrative begins with the

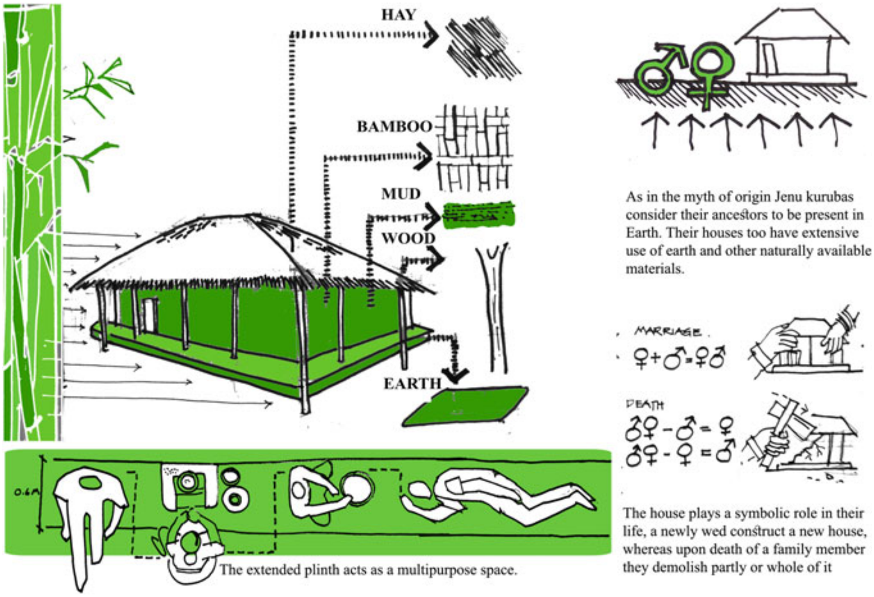

Fig. 9 Socio-cultural schema

death of villagers and ends with marriage of the two brothers. Similarly, according to their customs, newlywed couples construct a house, and demolish it upon death of family member.

The 'mouse story' gives an understanding of their lifestyle, simplicity, and accepting life the way it comes. The use of naturally available local materials in their purest forms without any processing or transforming them also adds to that their built forms are product of culture as much as they belong to nature (Fig. 9).

6 Conclusion

In this paper, the design principles of vernacular architecture have been observed and analyzed through cultural perspective. The correlation and logical relations as observed in narratives can be deciphered as few of the design principles influencing the architecture of a locale (Fig. 10). The study concludes that the principles and attributes of vernacular architecture are 'structural' which are observed in terms of oppositions, logical relations and correlations present in the geographical, socio-cultural, cosmological and techno-economic schemas and the system within each society works towards regaining the equilibrium to contain itself and create a balance between nature and culture. It also ascertains the fact that the human thinking is structured and is composed of logical oppositions and correlations as observed in the narratives. The study also supports that the tangible object category is not devoid of cultural influences but ingrained with deep meanings that can be

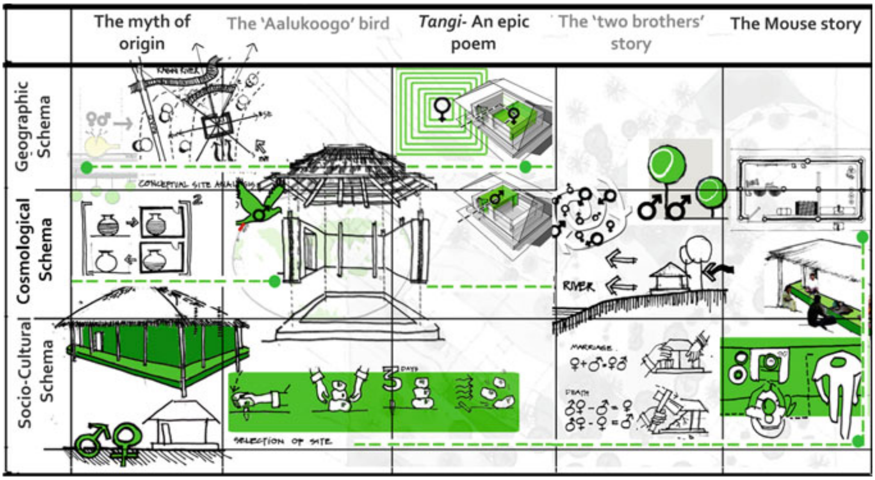

Fig. 10 Chart showing relationship of narratives and schemas

realized through understanding of other cultural aspects. Likewise, it also proves that the design decisions are not only dispersed horizontally in a period of time, but are also chronological; influenced from ancestral thoughts within a community. Similar study could be conducted to understand the other objects of material culture as in the field of product, furniture design etc. among communities.

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Form and Colour—Two Basic Elements of Design

S. Saleem Ahmed and B. Gurumoorthy

Abstract There is no consensus among the designers and design educators on the number of design elements. For well over 100 years of formal design education, design students are trained to use varying number of elements in their pursuit of designing products. In the design literature, there are different sets of design elements mentioned for the purpose of designing products. This inconsistency has often led to confusion among design students and designers about what really are the elements. This paper is an attempt to bring some clarity to this state of confusion. This also explains why there are varying number of elements used by designers and how one can expand the basic elements of design, Form and Colour, into varying number of elements for meeting their purpose. Results of this study will help designers to make use of the popular method of designing with more clarity and customize it to suit one's requirements.

Keywords Design elements · Design principles · Form · Colour

1 Introduction

There is no consensus among the designers and design educators on the number of design elements [1]. According to Lauer [2], who wrote a book on Design Basics, "no two designers will ever agree on the same list of design elements and principles or on which are which". There has not been any work on finding why there are many design elements and principles. So, this gap is partly being filled up through investigation on the design elements in this paper.

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Chapman [3], while describing the process of designing, stated that, “When artists plan their work, they must see and think about the elements and principles of design. The elements of design are: line, shape, color, texture, and value (light and dark). Artists also use ideas known as principles of design to plan their work. A principle of design is a guide for relating the visual elements. Some principles of design are: balance, rhythm, proportion, pattern, unity and variety.”

For well over 100 years of formal design education, design students are trained to use varying number of elements in their pursuit of designing products. In design literature, there are different sets of design elements mentioned for the purpose of designing products. This inconsistency has often led to confusion among design students and designers about what really are the elements. This paper is an attempt to bring some clarity to this state of confusion. This also explains why there are varying number of elements used by designers and how one can expand the basic elements of design into varying number of elements for meeting their purpose.

Elements and Principles Approach to design has been the method used widely by art and design educators throughout the world since the beginning of 20th century [4–8]. Kim [7] in her studies on the history of design theory in art education observed that, “the elements and principles of design have taken a firm place in various art curricula, textbooks, and national and state Visual Arts Standards” and she concluded that, “I do not expect that design elements and principles will disappear as aspects of art education in the fore-seeable future, or that their disappearance would be desirable”. Nowadays the boundaries of the domain of design are fast expanding and many new branches of design such as interaction design, web design, and app design are being introduced. It is important to adapt the existing elements and principles method to suit the needs of the newer branches of design.

2 Overview

Works of 12 authors who have majorly contributed to the field of design education since the beginning of 20th century have been considered. The design elements proposed by them have been analyzed. In this paper, attempts have been made to find why there has been no consensus and find out if there are any universal design elements possible. These have done by defining the design elements, criteria-check on the proposed elements, and categorizing the accepted design elements based on their function/nature/characteristics. Form and Colour are the basic design elements that finally emerge out of the analysis. The results are discussed and the recommendations for application to different branches of design are suggested.

3 Assumptions and Methods

When people engage with products, it is typically a multi-sensory experience. In addition to product's visual form, other product qualities like tactile, auditory, sometimes olfactory and gustatory are also used in a product experience. However product's visual form is considered particularly important for the following reasons:

(a) Vision is the dominant sense for majority of the people [9]
(b) Vision is a sense that is effective over distance and because of this products are typically seen before they are touched [10]
(c) Consumers approach a product to explore its non-visual qualities because often the product's visual form initially attracted them [11].

Perhaps because of these reasons, the majority of the literature focusses on visual aspects in comparison to other senses. Visual aesthetics and visual perceptions are commonly used terms in the literature. For the purpose of this paper, assumptions and definitions are made based on the dominance of the visual sense.

3.1 Definition of a Design Element

Any discrete visual and/or tactile entity is considered as a design element. A design is composed of several design elements. Pixels, Points, Lines, and Surfaces are used for constructing a design in the virtual media. They are building blocks and not design elements. At a micro level, Atoms are building blocks. Traditionally design elements are the ones used for composing the appearance or styling of a new design.

Design elements are unit-less entities. So, Length and Width cannot be design elements. Design elements are perceived through visual (optical) and/or tactile senses. Design elements are the optimal independent visual and/or tactile entities for a particular domain of design. They are either individually or collectively account for all that we see or feel in a product design.

3.2 Methods

Major contributors to the knowledge base of design aesthetics, design education, and design philosophy over the last about 100 years have been considered. All the design elements as proposed by these authors have been tabulated and analyzed. They have been sequenced to one order, checked against the definition of design elements, and categorized according to their nature/characteristics. The results were observed and checked for any patterns.

4 Analysis

Dow [12] authored a book on Composition in 1899. This was one of the widely followed books for formal training of artists and designers in the first half of 20th century. Subsequently Denman Ross authored a book called The Pure Design in 1907 [13]. The third one was on Art Education for High Schools authored by Louis Prang in 1908 [14]. All these authors proposed three design elements—Line, Tone, and Colour. These books ran into several editions and for decades these were the ones referred. In 1972, Malcolm authored a book on Design Elements and Principles [15]. Several publications came soon after. We have taken 12 authors, including the above four, who have contributed majorly to the field of Design Aesthetics/Art Education since 1900. Table 1 lists all the different authors and what they proposed as design elements. The order of sequence of the design elements is the same as what the authors have originally proposed. Johnson [1] said, "There is very little consensus as to what the design elements and principles really are, or what they mean". Table 1 confirms her observation.

4.1 Sequencing of All Design Elements to One Order

We notice that the sequence of the order of design elements is not same for all authors. For clarity and the ease of comparison, we have first rearranged the list of design elements in the following sequence—Space, Point, Line, Type, Surface, Texture, Shape, Form, Tone, Colour and any other. The arrangement is based on the tactile and visual qualities of the design elements. The resultant arrangement is given in Table 2.

4.2 Checking of All Design Elements Against Definition (Criteria-Check)

All the design elements were checked against the criteria for design element as given in Sect. 3.1. As a result, some of the tabled elements such as length, direction, position, orientation, size, dimension, and illusion of motion were disqualified as design elements in our list and marked out with the use of gray colored blocks. The resultant set of design elements are given in Table 3.

For the subsequent analysis, these so called marked out elements were not considered. The ones that meet the criteria for the design elements were categorized based on the function/nature/characteristics. This is to identify if there are any patterns in the agreed design elements.

In Table 4, all the design elements listed are after they have been sequenced, screened, and categorized. There are nine sets of design elements present in the

Table 1 Comparative study on design elements

Name of authors, title of the work, year of publication [reference no.]	Arthur Wesley Dow, Composition, 1899 [12]	Denman Ross, Theory of pure design, 1907 [13]	Louis Prang, Art education for high schools, 1908 [14]	Malcolm, Design: elements and principles, 1972 [15]	Lauer, Design basics, 1979 [2]	Frank Young, Visual studies, 1985 [16]	Wallschlaeger and Snyder, Basic visual concepts and principles, 1992 [17]	Lori Siebert and Lisa Ballard, Making a good layout, 1992 [18]	Marjorie Elliott Bevlin, Design through discovery, Belmont, 1994 [19]	Francis Ching, Architecture: form, space, and order, 1995 [20]	Ocvirk, Stinson, Wigg, Bone, Cayton, Art fundamentals, 2002 [21]	Poppy Evans and Mark Thomas, Exploring the elements of design, 2004 [22]
Design elements	Line	Line	Line	Space	Illusion of space	Line	Point	Line	Line	Point	Line	Space
	Notan (tone)	Tone	Tone	Line	Line	Form	Line	Shape	Space	Line	Texture	Shape
	Colour	Colour	Colour	Shape	Shape/form	Tone	Plane	Texture	Shape/form	Plane	Shape	Line
				Form	Color	Texture	Volume	space	Texture	Volume	Value	Size
				Color	Value	Color	Tone	Size	Color	Length	Color	Color
				Value	Texture		Color	Value		Form		Texture
				Texture			Texture	Color		Shape		Typography
				Illusion of motion			Shape			Size		
				Rhythm			Proportion			Texture		
							Dimension			Color		
							Direction			Orientation		
										Position		

Table 2 Comparative study on design elements

Name of authors, title of the work, year of publication [reference no.]	Arthur Wesley Dow, Composition, 1899 [12]	Denman Ross, Theory of pure design, 1907 [13]	Louis Prang, Art education for high schools, 1908 [14]	Malcolm, Design: elements and principles, 1972 [15]	Lauer, Design basics, 1979 [2]	Frank Young, Visual studies, 1985 [16]	Wallschlaeger and Snyder, Basic visual concepts and principles, 1992 [17]	Lori Siebert and Lisa Ballard, Making a good layout, 1992 [18]	Marjorie Elliott Bevlin, Design through discovery, Belmont, 1994 [19]	Francis Ching, Architecture: form, space, and order, 1995 [20]	Ocvirk, Stinson, Wigg, Bone, Cayton, Art fundamentals, 2002 [21]	Poppy Evans and Mark Thomas, Exploring the elements of design, 2004 [22]
Design elements				Space	Illusion of space		Point	Space	Space	Point		Space
	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line
	Notan (tone)	Tone	Tone	Texture	Texture	Texture	Plane	Texture	Texture	Plane	Texture	Typography
	Colour	Colour	Colour	Shape	Shape/form	Form	Volume	Shape	Shape/form	Volume	Shape	Texture
				Form	Value	Tone	Texture	Value	Color	Length	Value	Shape
				Value	Color	Color	Shape	Color		Form	Color	Color
				Color			Tone	Size		Shape		Size
				Illusion of motion			Color			Size		
				Rhythm			Proportion			Texture		
							Dimension			Color		
							Direction			Orientation		
										Position		

Table 3 Comparative study on design elements

Name of authors, title of the work, year of publication [reference no.]	Arthur Wesley Dow, Composition, 1899 [12]	Denman Ross, Theory of Pure Design, 1907 [13]	Louis Prang, Art Education for High Schools, 1908 [14]	Malcolm, Design: Elements and Principles, 1972 [15]	Lauer, Design Basics, 1979 [2]	Frank Young, Visual Studies, 1985 [16]	Wallschlaeger & Snyder, Basic Visual Concepts and Principles, 1992 [17]	Lori Siebert & Lisa Ballard, Making a Good Layout, 1992 [18]	Marjorie Elliott Bevlin, Design through Discovery, Belmont, 1994 [19]	Francis Ching, Architecture: Form, Space, and Or-der, 1995 [20]	Ocvirk, Stinson, Wigg, Bone, Cayton, Art Fundamentals, 2002 [21]	Poppy Evans and Mark Thomas, Exploring the Elements of Design, 2004 [22]
Design elements				Space	Illusion of space		Point	Space	Space	Point		Space
	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line
	Notan (tone)	Tone	Tone	Texture	Texture	Texture	Plane	Texture	Texture	Plane	Texture	Typography
	Colour	Colour	Colour	Shape	Shape / form	Form	Volume	Shape	Shape / form	Volume	Shape	Texture
				Form	Value	Tone	Texture	Value	Color	Length	Value	Shape
				Value	Color	Color	Shape	Color		Texture	Color	Color
				Color			Tone	Size		Shape		Size
				Illusion of motion			Color			Form		
				Rhythm			Proportion			Size		
							Dimension			Color		
							Direction			Orientation		
										Position		

Gray coloured elements Not considered as they are not meeting the criteria-check

table. We notice that there are elements related to the form and colour present in all of them. Elements that are related to form have visual and tactile qualities whereas elements that are related to colour have only visual qualities. For the ease of better clarity and for ease of comparison, we have given warm colours to all the elements related to Form and cool colours to all elements related to Colour. Then what emerges is given in Table 4.

Table 4 Comparative study on design elements

Name of authors, title of the work, year of publication [reference no.]	Arthur Wesley Dow, Composition, 1899 [12]	Denman Ross, Theory of Pure Design, 1907 [13]	Louis Prang, Art Education for High Schools, 1908 [14]	Malcolm, Design: Elements and Principles, 1972 [15]	Lauer, Design Basics, 1979 [2]	Frank Young, Visual Studies, 1985 [16]	Wallschlaeger & Snyder, Basic Visual Concepts and Principles, 1992 [17]	Lori Siebert & Lisa Ballard, Making a Good Layout, 1992 [18]	Marjorie Elliott Bevlin, Design through Discovery, Belmont, 1994 [19]	Francis Ching, Architecture: Form, Space, and Or-der, 1995 [20]	Ocvirk, Stinson, Wigg, Bone, Cayton, Art Fundamentals, 2002 [21]	Poppy Evans and Mark Thomas, Exploring the Elements of Design, 2004 [22]
Design elements				Space	Illusion of space		Point	Space	Space	Point		Space
	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line	Line
	Notan (tone)	Tone	Tone	Texture	Texture	Texture	Plane	Texture	Texture	Plane	Texture	Typography
	Colour	Colour	Colour	Shape	Shape / form	Form	Volume	Shape	Shape / form	Volume	Shape	Texture
				Form	Value	Tone	Texture	Value	Color	Length	Value	Shape
				Value	Color	Color	Shape	Color		Texture	Color	Color
				Color			Tone	Size		Shape		Size
				Illusion of motion			Color			Form		
				Rhythm			Proportion			Size		
							Dimension			Color		
							Direction			Orientation		
										Position		

Warm colours Elements related to form

Cool colours Elements related to colour
Gray colours Not considered as not meeting criteria

5 Results and Discussion

5.1 Form and Colour

Interestingly in all the sets of design elements, we notice that there are representations from two areas—Form and Colour. Every design element mentioned is actually an extension of either one of these two—Form and Colour. In other words, we can deal with only two elements for tackling design problems. But that would complicate the matters as referring and composing solutions becomes difficult. So, for achieving certain visual effect in the composition and/or to apply different design principles conveniently, having different extensions of Form and Colour becomes necessary.

Interestingly though several authors have proposed different sets of design elements and principles, they also have proposed means to compose design solutions (read 'new designs'). All were complete by themselves.

Also which area of design, one is dealing with for a solution, necessitates as what may be taken as design elements.

Following are some of the well-known areas of design: Industrial design, Automobile design, Packaging design, Furniture design, Interface design, Web design, App design, Interaction design, Ceramic design, Interior design, Fashion design, Textile design, Graphic design, Typography, Photography, Animation design, and Communication design.

Each domain or area of design has a slightly different way of analyzing and synthesizing during the course of problem-solving (read designing). All cannot deal with one set of design elements. For example, typography is treated as a separate element in communication design whereas in ceramic design or interior design, typography (or type) is treated as kind of line, which is by itself a design element. Another example can be pattern. In the domain of textile design or fashion design pattern is required as a design element because the designers deal with it regularly for their design expressions. Whereas pattern is not considered as a separate design element in the domain of industrial design or furniture design as the frequency of usage is limited.

5.2 Recent Designs Are More Tactile

In Table 4, the works of different authors are chronologically arranged. We notice that in recent times, the number of design elements, though from one of the two groups (form and colour), have increased. There are more elements on the Form group (warm colored ones). This group is more concerned with the tactile and optical (visual) qualities of the products. The number of elements listed by each author is also an indication of the complexity that the elements can possibly handle. So, could we conclude that the recent designs have more tactile features than the ones that came out, say until 1960s? It may be premature to conclude without analyzing with sufficient data, but we can take it as a pointer for exploration.

6 Conclusion and Recommendations

Based on the studies here, we can conclude that *form* and *colour* are the basic elements with which composition of appearance or styling is done for a design. One can extend the form into line, texture, and shape and the colour into tone, value, transparency, and brightness. These extensions are based on what area of design, like Product design and Interface design, one is dealing with. It is not important to limit the number of design elements; as long as a designer is comfortable to deal with it, any number of elements which are extensions of form and colour is alright. This also explains why there are varying number of elements used by designers and how one can expand the basic elements of design into varying number of elements for meeting their purpose.

Also it is recommended that terms like length, size, dimension, direction, and position shall not be used as design elements as they fail to meet the conventional criteria for being termed as design elements.

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Spokes Characters of Mascot and Young Consumers' Perspective Particular Understanding

Preeti Yadav, Dandeswar Bisoyi and Debkumar Chakrabarti

Abstract Mascots are popular way of promoting brands. A study was conducted in India compromising of 150 students to understand the spokes influence the way young consumers perceive products. Abased on the information collected, alternative spoke-mascot relationships have been tried out. Experiments confirm that effective mascots should consider the combinations of physical design elements, color, and cultural preferences of the targeted audience.

Keywords Element identity · Character imitation · Design application

1 Introduction

A mascot is a person, animal, or object, which is used as fictional representative for consumer products. Mascots are incredible marketing tools. Mascots brand elements helping people to better remember the company and the product. Spokes-characters appear in many promotions campaigns. The spokes-characters of mascots have an impact on the brand and corporate identity [1]. Spokes-characters of mascots are frequently used by food industry. The process food organization basically target young people who enjoy taking the types of foods that they offer. The main aim of the study is to investigate the perception of young consumers on spokes-characters with reference to the Indian processed food.

Spokes-characters are elements of branding that help consumers to better remember the company products. Mascots are based on objects, animals and people to help people to identify with a product, remember it and understand the products

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better [2]. Mascots have been successfully used to advertisers and promote the brand of companies. The mascots have a big advantage over the spokesperson [3]. The mascots do not age, and they are ageless brand representative of an organization. An organization can use a mascot design for ages, and it will stock in the minds of consumers enabling them to identify the brand once they come across the mascots. Unlike company spokespeople, mascots do not engage in affairs that can damage the brand. When companies use individuals to represent a brand the affairs of the people are associated with the brand. However, mascots will not engage in affairs that can damage the brand such as making hateful comments [1]. The mascots will make money for a company and enable an organization to develop a closer relationship with consumers.

In the food industry, the design of the mascot is very vital. It is important to get the right mascot design to ensure that the company sends the right message and attracts young consumers. Garretson and Niedrich [1] show that there are a number of aspects of the design that is important for mascot targeting young consumers. The first one is the personality. The food industry is competitive and it includes some international companies such as MacDonald's, and KFC, Fig. 1. For a company to stand out from its competitors, it must develop a mascot that has a distinct personality. The personality of mascot should be a representation of the company. It should communicate to the audience the main aim of the organization. Some companies that localize their foods will try to create a mascot that includes the culture of the targeted audience.

This can be represented in the dress code. According to Garretson and Burton [2], the personality of the mascot is important. It is how the consumers will perceive the organization hence it is important to develop a personality that is distinct from competitors and that represents the value of the organization. The design of the mascot should represent the overall values and goals of a company [4]. This is captured in the way that mascot looks and carries itself. An organization that establishes a mascot that plays a big role than the logo and it has a speaking voice must ensure that the voice and action of the mascot represent the strongholds of the company. According to Yadav et al. [5], the mascot design must be flexible. The

Fig. 1 MacDonald and KFC mascots

most successful design is flexible, and they get out of their way to make consumers remember. When creating a mascot design, it is important to understand that it should have room for growth, and it can be altered as time changes to continue reflecting the goals of the company [6].

Today, the young consumers are familiar with the social media. The young consumers aged between 16 and 24 years are frequent users of the social media the social media is the new playground for marketers that wish to attract young consumers [7]. Brands are now using the social media to make mascots stars of their advertisements. Yadav et al. [5], also focus on showing that mascots are now part of the social media visual marketing strategy of organizations that focus on young consumers. The social media is being used to develop stories about the mascots helping the company to engage more people with the brand.

Patterson et al. [7] argue that mascots are more effective when used with other marketing strategies. Food companies should not only rely on spokes, but they should include other promotional strategies to market products. There should be different marketing strategies, but the mascot should be tied to the overall brand message. Amul girl (Fig. 2) is the good example of that, where companies can use the mascot together with other promotional tools such as logos.

Fig. 2 Amul girl, a successful brand identity

Fig. 3 Haldiram logo, Indian popular food enterprise

The present study looks at understanding the spokes characteristics and their influence the way young Indian consumers perceive with reference to Haldiram, Fig. 3, Indian product and its brand identity.

2 Methodology

The main study emerged from the results/observation of then pilot studies concluded prior to the main experiment. All the questionnaire to the participants were validated by treating them with chronbach 'α' statistics and upon having a significant reliability only, the questionnaire was considered for administration. Current Study aimed to young consumers with the age group of 20–25-year-old. This approach allows this investigation not only to analyze the current situation on the Indian food market but also to provide recommendations and formulate forecast because the trends noticed among the members of the young consumers group has clearly have a high potential of becoming the common trends in marketing in the nearest future. To investigate the young consumer perspective on spokes-characters, this study was conducted in two part first was conducted in design school of Delhi. Where the group of 20 students were part of this study before designing Haldiram's mascot gave them proper brief of brand and their key elements such as Rajasthani Origin, Bikaner, trust, taste, quality, traditional, Indian flavours, ethnic, Exclusive (While creating the character the following Keywords were kept in mind).

Second study was conducted in Delhi University with the sample of 150 students was selected. The sample consisted of undergraduate and postgraduate students. It compromised of both girls and boys who fall under the age group 20–25 years. Within the sample, the students were divided into equal five groups of 30 participants in each group and these participants selected from five different academic background. Showing the Slide of 15 different designs of Halidram's mascots, Fig. 4 and in this study structural questionnaire was used. In the first part of the questionnaire participant select 1best and 1worst design as per their own perception and second and third part of questionnaire there were twenty options where they had to choose five answers which support the best design and worst design.

Globalization has encouraged various food companies to move to the Indian market to capture various opportunities. International players such as MacDonald's and KFC have influenced the Indian market. The foreign companies have come

Fig. 4 Haldiram mascot design, 15 alternatives proposed

with mascots with an aim of influencing people to purchase the products. The study wants to examine the influence of mascots with Indian identity on the young consumers. The study will focus on Haldiram which is a fast growing a popular food enterprise of Rajasthan origin. Certain products have been selected, and various spoke characters for these Haldiram products have been identified. This research will be used to examine how the young consumers rank the representation of the spokes with different designs and which spokes will enhance their perspective of the brand.

3 Results and Discussion

The students identified major elements of the Rajasthan origin. The students could identify with the various Indian traditions. The mustache was a major mark on the various mascots is a signature of the Indian tradition which shown in Fig. 5. The mustaches are of different types, and each region has its type of mustache.

The turban is a reflection of the traditions of the Indians, Fig. 6. By dressing the mascot in Indian traditional clothes, Fig. 7, it brings out the history of the brand. It shows that the brand has an Indian origin, and it has been in served the Indian market for many years. The Rajasthani Halwai represented the traditional Indian.

The mascot is a true representation of the origins of the Haldiram. In Fig. 8, the man is wearing a typical Rajasthani turban, and coat. The mascot is holding a sweet and has made a happy expression. The mascot reflects on the identity of the Haldiram. The turban is a representation of the culture of the Indian of the people. The traditional representation of the Indian culture enhances the perspective of the young consumers as it brings out the ethnic values of the Indians. The sweet also

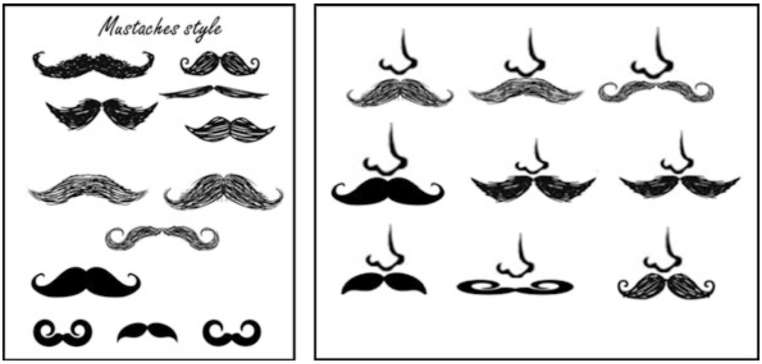

Fig. 5 Mustache are major signature of the Indian tradition

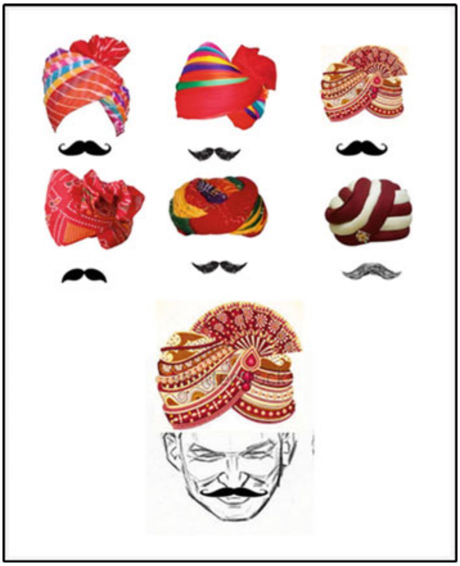

Fig. 6 Represent of turban is a reflection of the traditions of the Indian

Fig. 7 Representing Indian traditional clothes

indicates that the person enjoys the brand. The brand's main foundation was based on creating an enjoyable experience. Holding the sweet and the happy expression shows that the person is enjoying the brand. The gesture of the hand depicts the authenticity and the quality of taste of food. The students identified the traditional taste composed of sweet and flavors. The students also identified the quality of the brand using the mascot and concluded that the brand can be relied on.

The feedback and results of the study indicate that spokes have an impact on the way young consumers perceive a brand the combinations of various aspects of the mascots such as design, color, and miscellaneous features increase the effectiveness of non-verbal communication with young consumers hence enhance more favorable brand attitudes.

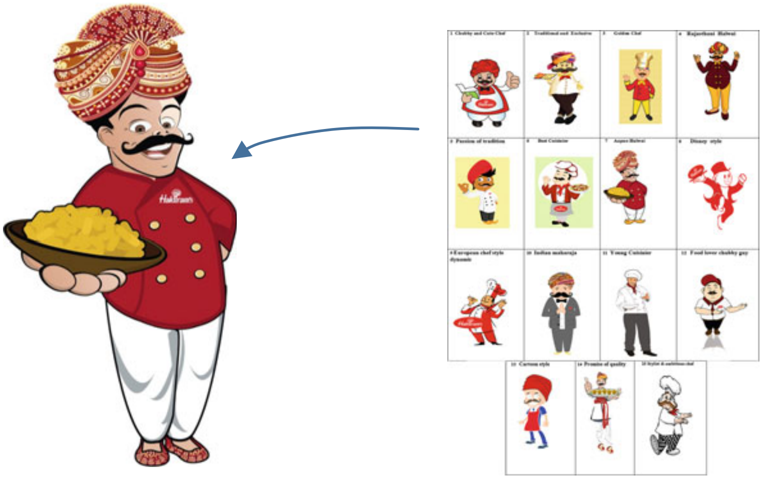

Fig. 8 Aapno Halwi proposed mascot for Haldiram brand

4 Conclusion

Spokes with socio-cultural elements tagged to them construct the mascot and influence young consumers perceive a product to select. The young buyers can analyze the elements of the brands, and their contextual views are vital in designing the mascot for brand identity. It is important to establish brands that are in line with the culture and the perspective of the targeted audience. Haldiram mascot designed here in is still awaiting feedback refinement from various targeted user groups, and prototype development and market trial.

Appendix

Select the BEST and the WORST DESIGN (in your opinion) as per your imagination/visualization of the prospective design of Haldiram's Spoke-Character (Mascot) based on the following characteristics:

- FIGURATIVE is related to the capacity that a stimulus has to represent a shape containing a subject, which is recognizable beyond its purely visual lines. In other way, figurative is associated with representative forms.
- SYMMETRY is associated to the classical ideal, clearly associated to balanced identity, equilibrium and the very notion of beauty.
- ANGULAR shapes have one or more sharp angle(s).

Choose Five(5) Best fitting Characteristics of the design best in your opinion

1	This is Figurative spoke-character
2	Spoke-character expression emphasizes on the authenticity
3	Gesture of the hand conveys the message of quality and taste of the food
4	Face expression emphasizes on the authentic taste and pleasure of eating
5	Spoke-character designed is a perfect blend of quality and tradition as well, while conforming to the International standards of hygienic food
6	The design of the spoke-character would be a combination of modern and traditional look
7	Spoke-character has a Rajasthani attire with moustache, turban etc.
8	Most of the designs were inspired by the words 'Halwai' and Chef
9	Red colour is selected for the spoke-character as it is the colour of the 'Haldiram's' logo
10	Red is an appetizing colour
11	Vibrant color used in turban signifies the influence of Rajasthan
12	Colour is the key factor of attraction for any spoke-character
13	Character wearing traditional Indian cloths to relate with the brand and its history
14	Moustache of character depicts particularity of Rajasthan
15	The folded hands, showcase the Indian culture of greeting with a 'Namaskar', thus attracting people with an emotional/personal touch
16	Spoke-character reflects the traditional Rajasthani attire
17	Spoke-character design depicts pride
18	Expansion of business (brand) crossed several international boundaries
19	The concept of the character is to denotes the standard quality of the Haldiram's products
20	Haldiram's is synonymous with taste, hygiene and innovation

Choose Five (5) Most Undesirable Characteristics of the design Worst in your opinion

1	This is Figurative spoke-character
2	Spoke-character expression emphasizes on the authenticity
3	Gesture of the hand conveys the message of quality and taste of the food
4	Face expression emphasizes on the authentic taste and pleasure of eating
5	Spoke-character designed is a perfect blend of quality and tradition as well, while conforming to the International standards of hygienic food
6	The design of the spoke-character would be a combination of modern and traditional look
7	Spoke-character has a Rajasthani attire with moustache, turban etc.
8	Most of the designs were inspired by the words 'Halwai' and Chef
9	Red colour is selected for the spoke-character as it is the colour of the 'Haldiram's' logo
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11	Vibrant color used in turban signifies the influence of Rajasthan
12	Colour is the key factor of attraction for any spoke-character
13	Character wearing traditional Indian cloths to relate with the brand and its history
14	Moustache of character depicts particularity of Rajasthan
15	The folded hands, showcase the Indian culture of greeting with a 'Namaskar', thus attracting people with an emotional/personal touch
16	Spoke-character reflects the traditional Rajasthani attire

(continued)

(continued)

17	Spoke-character design depicts pride
18	Expansion of business (brand) crossed several international boundaries
19	The concept of the character is to denotes the standard quality of the Haldiram's products
20	Haldiram's is synonymous with taste, hygiene and innovation

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The Making Affect: A Co-created Community Methodology

Fiona Hackney

Abstract This paper explores research undertaken as part of the Arts and Humanities Research Council (AHRC) funded project: Co-producing CARE: Community Asset-based Research & Enterprise, which worked with community groups to explore how craft, as a practice and a methodology, might promote community agency and build assets through co-creative making, learning and sharing. It draws on a range of discourses, theories and practices from social design and design thinking, to ethnography, embodiment, cooperation and community agency.

Keywords Activism · Amateur · Agency · Co-creation · Crafts · Community · Ethnography

1 Introduction: *Making* Community: The CARE Project

Community is a slippery term. Writing about community heritage, Crooke [1] claims that today it can cohere around 'shared interests and experiences', which might act as 'motor for collective action'. Paying attention to power relations, Alison Gilchrist argues for the creation of new 'circuits of power' and sustainable networks that promote access and inclusion and are accountable to communities [2]. The cultural theorist Bauman [3], meanwhile, maintains that the current increased interest in the idea of community is generated by a rising sense of insecurity and threat, whereby community represents a means to reverse uncertainty because it is thought to bring protection and wellbeing. To understand how community exists or might come into being through craft and, more especially what we came to term creative making, was a central aim driving Co-producing CARE: Community Asset-based Research & Enterprise, a project funded by the UK Arts and Humanities Research Council as part of the Connected Communities research programme [4]. Questions of shared interests and experience, power relations,

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insecurity and threat, and how collective making might variously promote, destabilise or address these concerns underpinned the research.

Connected Communities supports research that examines the changing place of communities in our lives, their role in encouraging health, economic prosperity and creativity in the past and the future. Co-producing CARE was one of a number of projects that used practice-based research methods to explore how creativity might serve as a means of co-production to enhance and support communities. It focused on craft processes and the ways in which they might, or might not, promote collaboration to build community assets and agencies. A partnership between Craftspace Birmingham, Voluntary Arts England, Bealtaine Festival (age and creativity) Dublin, Falmouth and Northumbria Universities, the project worked with amateur hobby craft groups and activities as knitting, crochet, sewing and embroidery that are undertaken voluntarily and for pleasure. Creative hobbies involve individual, family and community knowledge and modes of social engagement, they absorb people, draw them together, and can be both fulfilling and fun yet, too often, these qualities are dismissed or ignored. Our argument is that by working co-productively alongside researchers amateur makers could co-creatively interrogate the making process as a collaborative resource, which enables them not only to share crafts skills and knowledge, but also to build assets, resilience and confidence beyond the craft circle in the wider world as, for instance, volunteers or community activists, retrain or start a small business or social enterprise [5]. Social activism takes many forms and there is a rich history of cultural struggle within social movements, most recently for minority rights and 'democracy from below'. Research suggests that a participatory, co-creative approach is key to developing greater self-awareness and confidence amongst communities and individuals to take action and change their environment and life experiences [6]. As people become more critical of their own conditions and circumstances, albeit 'quietly' in ways that are embedded in, and entangled with, the rhythms and structures of daily life, they will feel more willing to challenge accepted norms or practices [7].

2 'I've Got Stitch Club': The Quiet Activism of Amateur Crafting

A central aim of CARE was to understand how creative making in general and stitch in particular (the processes of sewing, knitting and embroidery) might serve as a metaphor, a means and a methodology for understanding and promoting agency [8]. Our thinking drew on the history of crafts and current practice-based research. Before considering some of the findings from a selection of CARE workshops it is helpful to outline some of the ideas and existing research that informed this work.

Whilst conventional conceptions of craft as education, amusement or therapy have served to promote crafts practice in various contexts, they perpetuate a menial, trivial or ‘warm and fuzzy’ view of manual creativity and are limited in viewing individuals as ‘passive demographic containers’ for improvement, entertainment or healing. In sharp contrast to this, the crafts have a history of use for overtly political ends [9]. Newmeyer, for example, notes how the quilting bee served as a subversive space for promoting women’s suffrage; how nineteenth-century abolitionists used quilts both to carry political messages and to raise money for their cause; and how a range of contemporary ‘craftivist’ projects have used vehicles such as quilting and knitting to highlight and protest against global inequalities, interventionist foreign policy, or political indifference to the AIDS epidemic [10]. On one hand crafting is seen as unadventurous, tradition-bound and apolitical, while on the other it is seen as radical and unconventional. Emergent scholarship is starting to challenge these stereotypes, enquiring into the small-scale empowering potential of making as a process bound up with connecting, reflecting and becoming, and a methodology that both can provide new insights and make things happen [11].

In a recent article about craft and ‘quiet activism’, Hackney draws on the current re-engagement with amateurism, as well as studies of ‘everyday creativity’, ‘serious leisure’ and ‘flow’ to explore the relationship between creative making, quiet activism and wellbeing [12]. She argues for the recognition of a new super-connected amateur maker who, freed from professional constraints and informed by a wealth of on and offline resources (citizen journalism, community broadband, online forums, social media), engages in quietly activist processes that open up new channels of value and exchange. The ‘new amateur’ is not necessarily new per se—there is a long history of amateur domestic crafts, for instance—but displays a new relationship with creative making and can harness personal and community assets in often surprising and productive ways. The quiet activism practised by amateurs, or professionals in an amateur context, is not an outspoken form of radicalism or critique, but rather a means of thinking and acting independently, staking a place in the world and making one’s voice heard. Rooted in everyday life, it arises from and responds to the lived experience of paradox, conflict, isolation, frustration, loneliness or illness and involves qualities of patience, discipline, ingenuity, and sometimes risk taking. The remarkable ‘Changi Girl Guide Quilt’, for instance, is a startling example of quietly activist sewing and embroidery which, not only helped young women maintain their spirits and a sense of identity during World War II, but also to survive under dreadful conditions [13]. Paying attention to the quietly activist processes of everyday making precipitates a reassessment of craft: its genres, institutions, practitioners, networks, protocols, practices, and the methodologies we use to understand it. Matthew Crawford in *The Case for Working with Your* Hands, for instance, calls for ‘a new anthropology … one that is adequate to our experience of agency’ and which ‘gives credit to the practice of building things, fixing things, and routinely tending to things, as an element of human flourishing’ [14].

Recent studies employ a range of methodological approaches including: anthropology, ethnography, film as auto-ethnography, linguistics and narrative theory, and co-design, as well as crafts theory [15]. These inform the research methods employed in CARE workshops—unstructured participant interviews, video and photographic documentation—to capture the experiential qualities of stitch, and explore the complex ways in which creative making can operate as a co-creative process. Textile researcher Emma Shercliff's work is particularly helpful in this respect. Examining the twin processes of 'social stitching' (with an embroidery group) and stitching alone, she noted the fluidity of these context-based practices, arguing for the centrality and specificity of the making process: its sensory qualities in response to materials; condition of absorption; and intuitive awareness of space inhabited by the body. Shercliff draws on her own experience of stitching to observe how the hand-eye-mind coordination of stitch cultivates a distinct form of attention to the self, allowing the individual to 'carve out time and space for introspective reflection' while embodying a shared knowledge of making, expressed through rhythm and pattern, that connects the individual with the group. Paying attention to the minutiae of making processes enables us to think about how individuals might connect with themselves and a group, suggesting metaphors for other processes of 'collaboration and integrity' or 'separation and isolation' [16].

Making, moreover, is bound up with verbal interaction: conversation and chat. Shercliff thinks carefully about the inter-relationship between making and conversation, while geographer Paul Gilchrist and colleagues proposed a new method of participatory community arts research (the collaborative stories spiral) that connects making with situated, mediated and remediated narrative [17]. No one, however, has considered how reflexive stitching might serve as a mode of co-created ethnographic research, an approach that emerged from one of the CARE communities based in Falmouth, Cornwall: a sewing group comprised of early career professionals, recent textile graduates and embroidery enthusiasts. As the meetings, which consisted of sewing and chat, progressed, the group became increasingly conscious of sewing as a repetitive, rhythmical, responsive, immersive and embodied practice, which slowed them down and unconsciously focused their attention on each other through the shared work. As co-researchers we considered how the embroidery process might serve as a mode of ethnographic practice: a method for self-reflexively paying attention to ourselves, our codes of behaviour and group interaction [18]. Building on notions of participant observation derived from ethnography and the researcher as embodied subject in auto-ethnographic work [19], we developed a system whereby, immediately after each workshop participants would record their thoughts, feelings and emotions, mood, bodily state, snippets of conversation and stories told, and render them as stitched notes (text and/or image) or mind-maps. These would be brought to the following session to aid collective reflection and analysis and build a bigger picture as the workshops progressed.

Acknowledging the quietly feisty and unruly aspects of amateur making invites some theorization of the individual capacity to use, contest or rework hegemonic top-down discourses from the bottom up. A member of the Falmouth sewing group, recounting her family's dismissive view of sewing as an activity for retired ladies, subverted this stereotype when she declared, 'I've got stitch club!': a textile version of 'fight club'. Michel de Certeau emphasized how individuals, confronted by the dictates of history, culture and institutions, contrive to engineer a little freedom, 'through a mobility that must accept the chance offerings of the moment' and 'vigilantly make use of the cracks that particular conjunctions open in the surveillance of the proprietary powers' [20]. This conception fits well with the playful wiliness and surprise tactics of contemporary craftivism and the quietly activist agencies of amateur craft [21].

3 Making Dialogues and Cooperative Communities: The CARE Method for Learning Through Sharing

In his recent publication *Together, the Rituals, Pleasures and Politics of Cooperation*, the sociologist Richard Sennett explored the social benefits of material craftsmanship as a mode of social cooperation. With its technological obsessions and restrictive work practices modern society, he argued, isolates people, breeds anxiety and de-skills. The challenge is to forge new forms of meaningful collaboration; a process fraught with difficulty which, if achieved, could help communities build dialogue and gain fresh insights [11]. 'Making dialogues', communicating solely through creative making, that is, became a structuring idea that informed the co-creative methodology for CARE's initial pilot phase. This took the form of a series of playful exchanges, or 'material consequences', whereby participants connected through a reciprocal 'call and response' process by making, sharing, exchanging, reflecting on, and learning from, textile artefacts [22]. A key learning point to emerge was that making is not always an easy process. Tensions emerged and far from bringing people happily together, differing views about creativity and textile skill, or the use of hand-making and digital technology, raised problems between (younger) students and (older) members of an embroidery group, whose members had established ideas about craft quality, standards and values [24].

Writing about community networks, Alison Gilchrist, who contributed to CARE as a project consultant, reminds us that informal networks can function as a collective resource *and* prevent the community acquiring new insights. She draws on complexity theory to argue for a model of the 'well-connected community' as an integrated and evolving system of networks, comprising diverse and dynamic connections, which 'tolerates difference, celebrates diversity, promotes equality and acknowledges mutuality' [23]. Gilchrist describes an intermediate 'edge of chaos' zone between rigidity and randomness in which forms of 'untidy creativity' operate. An idea that corresponds with Sennett's notion of a 'fraught, ambiguous zone of experience where skill and competence encounter resistance and intractable difference' [24]. The trick, in his view, is to respond to others on their own terms; a skill that involves the ability to listen well, behave tactfully, find points of agreement, manage disagreement, avoid frustration, and achieve interactions that are 'knitted together' though exchanges of difference: dialogic cooperation, or the location of common ground: dialectic cooperation or, most often, a combination of the two. Where we expected to find cooperation through a shared interest in making, we in fact discovered that making foregrounded difference and strongly held views, not only about craft but also about 'self' and 'other'. These notions of the craft group as a 'fraught ambiguous zone of experience', making as 'untidy creativity' involving different processes of dialectic and dialogic cooperation, emerged from the pilot phase. We realised that simply increasing connections through making was not enough. We needed to think more carefully about the power relations embedded in communities of practice and making exchanges, and that in order to do this participants had to be more proactively involved in designing the co-production process from the start.

'Making Things Together' (MTT), the second stage of the project, built on this learning and drew more explicitly on Freire's [25] understanding of pedagogy as praxis, whereby learning is transformed through a process of reciprocal dialogue in which people assert their voice and question dominant assumptions. The idea of 'making exchanges' had initially emerged from the idea that 'seeing oneself through another's eyes' might unlock unrecognised potential. MTT, which involved craft groups in Birmingham, Dublin and Falmouth, focused on different approaches to knowledge and skills exchange through collaborative making [26]. A range of novel strategies that re-conceptualised creative making as an intervention to promote reflection and reflexivity emerged. The three case study workshops below derive from the group located in the Poly arts centre in Falmouth, which comprised a mixture of trained arts and crafts professionals and amateur makers who met once a month for nine months or so. An ice-breaker workshop to identify participants and co-produce the project framework was followed by 'Making by Instruction', a session facilitated by Shane [27] an artist who works with participatory, collaborative engagement projects. His workshop was designed to playfully deconstruct conventional processes of learning through making. Participants then elected to facilitate their own co-creative workshops centred on different approaches to knowledge sharing through making.

To aid reflection, the research team, project partners and participants collaboratively developed two questions: 'What have I learnt? What have I shared?'. These were designed to help participants both look inwards, at their subjective experience and inner mental life, and outwards at their experience of connecting with others, within and between groups [28]. This material was gathered together in what became known as the 'doily archive' and employed in a series of short films hosted on the project website [29].

4 Making by Instruction: Embodied Instruction Through Shared Making

Drawing on studies of tacit knowledge [30], Waltener's workshop explored how spaces of innovation and creativity can open up when we intervene in conventional modes of instruction. Working in pairs, one person was asked to physically demonstrate a craft technique to their partner without the aid of text or diagrams; the image of finger knitting on one hand (Fig. 1a) is an example. Once this was

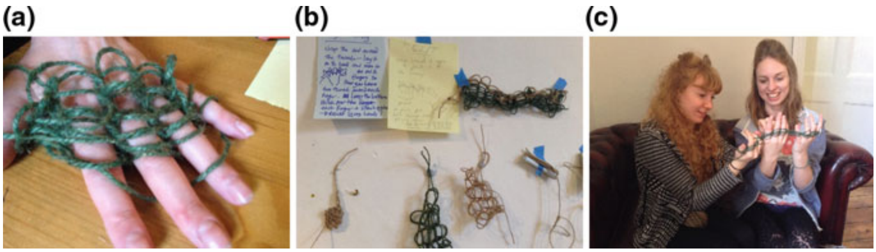

Fig. 1 Details of pieces created in the 'Making by Instruction' workshop. Photographed by the author

mastered, the recipient wrote down instructions for the process (using text and image) and passed these on to a second couple to interpret without benefit of the original demonstration (Fig. 1b). This process of networked activities and interrupted instruction opens space for 'untidy creativity', chance and innovation. The second pair in this example, for instance, unconsciously took the knitting process one step further by literally knitting themselves together; a highly appropriate material metaphor for the collective making process (Fig. 1c).

Watkins [31], in her study of pedagogy and accumulative affect, defines pedagogy as a 'process, whereby a sense of self is formed through engagement with the world and others and the affects this generates': a process that involves 'mutual recognition realized as affective transactions that at one and the same time can cultivate the desire to learn and the desire to teach'. Affect as a bodily phenomenon, 'the corporeal instantiation of recognition' through mutuality and feeling, 'fostering a sense of self-worth' [32] is arguably at the heart of the teaching and learning interactions involved in any community group, and particularly a sewing or knitting group where the closeness, physical and otherwise, coupled with the physicality of making, fosters a heightened sense of bodily connection and being. Eastop [33], writing about the folk art of string figure making—an activity that has much in common with finger knitting—argued for its use in understanding 'making as a process of embodiment and enacted knowledge' through the interaction between person and product, the process of making, and of demonstrating and accruing such knowledge. Embodiment, refers to the sense of knowledge stored within the body and the understanding that thinking and doing—or thinking through doing—are 'indissolubly connected through the current of practical action' [34]. Eastop, additionally, observed that the maker's body forms elements of the image, story and idea communicated in string figure making; the body, that is, is integral not only to the making process but also to what is made: the product and its meaning. Waltener's workshop deconstructed learning through making, showing how this can open up 'untidy' spaces in which new things happen. It also foregrounded the affective aspects involved: how knowledge is enacted through the process of embodiment and, as the finger knitters confirmed, bodies become intimately bound up with things (Fig. 1c).

5 Up Close and Personal: Learning and Teaching with I-Cord Knitting

Like string figure making I-cord knitting, which involves making cords, has a long history yet might easily be dismissed as ephemeral and unimportant. Craft artist Christiane Berghoff [35] chose it for her workshop because it is relatively easy to master and, therefore, an ideal exercise for reflecting on experiential making through learning and teaching. She selected three ways of cord-making, using knitting needles, crochet hooks and the lucette: a wooden fork shaped tool with two prongs. All group members learnt one technique by demonstration before skill-swapping and teaching it to others. Workshop photographs (Fig. 2a) demonstrate both moments of concentrated independent working, and light-hearted exchange in a form of 'dialogic play' or a 'dance of interaction' [36, 37]. The project film of the group records participants' reflections as they comment on the mindful, relaxed and playful aspects of the process. One participant, who describes herself as an 'explorer and a discoverer and a maker', reflects on being

> …completely immersed in the experience, so I'm just doing and I'm not thinking about anything else at all, and I'm letting my hands do it. It makes me feel better, as though I'm put back in the right place…I feel satisfied and fulfilled and as though I really have been through a process and come out the other end. So I have experienced some kind of new happening there, in between the learning and the making and the doing. [38]

Such testament which, in its description of immersion recalls the notion of 'flow', is a striking demonstration of the embodied nature of processual, enacted knowledge; the way in which self, doing, making, material culture and cognition, are completely interconnected and entwined. The evocation of taking a 'journey

Fig. 2 **a** Participants making at the 'I-cord Workshop'. **b** Flyer for 'The Embroidery Story-telling Circle' and **c** detail of the embroidered tablecloth. Photographed by the author

through process' in which new things happen in a space 'between the learning and the making and the doing', moreover, recall the chance spaces of invention in Waltener's workshop and Gilchrist's 'untidy creativity'.

In the film Berghoff emphasises the soothing, meditative qualities of such easy, repetitive activities and underscores crafting's potential to modify behaviour beyond the workshop, by helping us establish 'a new relationship with our things'. Before leaving this workshop it is important to note two observations that emerged when we ran it for academic participants during the AHRC Connected Communities Festival in Cardiff in 2014. Firstly, it became evident that teaching such craft techniques by demonstration necessitates a physical closeness which, to some extent, transgresses social norms, creating a new type of private, almost intimate, social interaction within a public space. And secondly, not everyone is soothed by such activities. Some male academics, in particular, who had no prior experience of domestic crafts, found the exercise challenging, almost threatening (one refused point blank to crochet); misgivings, nevertheless, that for those who took the plunge were soon allayed after achieving even a small degree of success.

6 The Embroidery Story-Telling Circle: Transitional and Boundary Objects, Dialogic and Dialectic Exchanges

CARE proposed that the craft group: its processes of coming together through making and talking and the artefacts produced, is not only a metaphor for collaboration, but can also forge processes of cooperation and perform individual and collective identities in particular ways. 'The Embroidery Story-telling Circle', a workshop facilitated by embroiderer Irene Griffin, set out to examine this process (Fig. 2b). The workshop, which involved participants sitting around a circular cloth, telling stories and stitching with one selected stitch and colour as the cloth was intermittently turned, was a crafty intervention to designed to explore relationship between storytelling and making, and how subjectivities are performed and worked through within a group setting. Sennett's ideas about dialogic (exchanges of difference) and dialectic (the location of common ground) cooperation informed our thinking, alongside ideas about the recognition of self through a process of affective differentiation, interaction and intersubjective engagement; the belief that subjectivity emerges through a series of interchanges mediated by 'transitional objects'; and the notion of the 'boundary object', which is 'at once material and processual'—not so much 'an edge or a boarder' but rather a 'shared space' where 'narratives can be situated, constructed, mediated and remediated' through time [31, 39, 40]. These ideas helped us conceptualize the embroidery group in terms of (1) the value of mutual recognition through affective transactions: group reciprocity, sociality, interaction, (2) how these are mediated through 'transitional objects': sewn items and associated equipment that (3) materialize recognition of self and other through an ongoing, iterative process of making, sharing, talking and reflective mediation and remediation.

Tensions emerged as some participants struggled to conform to the exercise, protesting about the limited colours and the requirement to work on a collective rather than an individual piece (Fig. 2c). As with the pilot project it was the members of an established sewing group who struggled most. Issues of taste, quality and authorship were raised which, in turn, shaped the stories participants told about their ‘lives in stitch’. Other participants used such strategies as humour to calm the situation. The energy ebbed and flowed as the group alternatively ‘storied’, conversed, sewed and reflected; a rhythm established by the repetitive cycle of stitching and moving on. Sennett argued that the trick to cooperation is to respond to others on their own terms, something that involves the ability to listen well, behave tactfully, find points of agreement, manage disagreement and avoid frustration. Such skills were variously conspicuous by their absence and appearance as the workshop wore on, establishing its own rhythm. Dissonance was gradually replaced by a quieter sense of cooperation as participants seemingly sewed their differences into the cloth. The sewing circle appeared to provide a safe space in which to express differences that were materialised in, and mediated through, stitch. It served as a process and artefact: a transitional and a boundary object, as differences were resolved, first dialogically (exchanges of difference), then dialectically (the location of common ground), which occurred less through conversation than the quiet act of making as cooperation replaced contestation.

7 Conclusion: Making Things Social: Community Agencies

Bruno Latour’s conceptualization of things as actors and actants in social networks has fundamentally changed how we think about connectivity, agency and our relationship with processes and things [41]. ‘Crafty’ interventions such as the ‘Making by Instruction’, ‘I-cord Knitting’ and ‘Story-telling Sewing Circle’ workshops activated particular forms of network where people interacted with, and through, people, processes and things. While we had begun the project anticipating an easy engagement through craft, we found something quite different, which may be encapsulated in the relationship between the two terms: ‘craft’ and ‘creative making’. The former signals the customary knowledge that we find in formal craft groups with established ideas about skill, aesthetics and value, while the latter indicates something more fluid or disruptive with less, or at least unexpected, rules. When the two come together, as they did in all the CARE workshops in different ways, they open up new possibilities for participants as they variously engage in Sennett’s ‘fraught ambiguous zone of experience’ or Gilchrist’s ‘untidy making’, and forge their own means of cooperation (dialogic and dialectic) by disagreeing, listening, sharing, learning, creating, paying attention, and finding points of connection to respond to others on their own terms. As such, the workshops demonstrate the potential power of conventionally marginalized amateur practices to help us co-creatively connect in communities, remake our social relations, rethink who we are and our capacities. A symbol of the tenacity and craftiness of the small in the face of the powerful, CARE suggests how the practice of making, which involves a commitment to being with others and a process of sharing, reflecting and interacting, can help people tell their stories, resolve differences, make sense of their everyday lives, experiences, histories and communities, challenge social norms and, above all, make things happen.

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Part V
Design Training and Education

Design Week: A Challenge for Designers and Medical Students

Juan Carlos Briede Westermeyer and Cristhian Pérez Villalobos

Abstract Health disparities continue to pose a challenge to lesser-developed nations. As a result, an interdisciplinary approach is needed to address this complex problem and develop innovative solutions. In the present study, design students and students in public health (whose curriculum provides few opportunities to work with design) participated in an interdisciplinary design workshop aimed at developing product solutions to issues faced in the healthcare sector. Twenty-one industrial design students and eight public health students were divided into heterogeneous groups, asked to identify a challenge facing healthcare professionals, and finally design an object-oriented solution. Initial conclusions show that students favoured the workshop's emphasis on innovative thinking across disciplines. Overall, the workshop promoted interdisciplinary dialogue from the outset and ensured that each and every participant contributed to the design process, thereby facilitating a view of design consistent with the procedures, requirements and limitations of students' context.

Keywords Creativity · Interdisciplinary · Collaboration · Design · Health · Education · Social role · Community

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1 Introduction

The present study explores the application of an academic workshop aimed at creating design solutions for problems facing the Chilean public health sector. Undergraduate design and public health students participated in the workshop. Activities sought to build capacity among students in object-oriented design by asking them to develop solutions to specific challenges facing the healthcare sector.

For this workshop, the topic of health was selected since access to healthcare is widely regarded as a basic human right among Latin American nations. Here, the state is seen as a guarantor of health and its citizens as rights-holders [1]. Unfortunately, in practice individuals with insufficient resources continue to face barriers to accessing efficient and effective care [2]. In this way, scientific advancements are viewed as necessary building blocks for innovation and development in the healthcare sector [3]. Indeed, since the 1970s a consensus has built around the role of scientific development as a necessary counterpart to technological solutions that improve economic and social conditions [4]. Now that the turn to “de-medicalization” of health research has opened the doors to other disciplines, another premise emerges: scientific and technological development should be addressed in an interdisciplinary manner [4]. Such an approach strengthens capacities and compensates for the shortcomings of each discipline, allowing for a more comprehensive understanding of healthcare provision that grasps the complexity of knowledge, which is inaccessible when addressed by isolated fields [5].

Approaching this opportunity in undergraduate education may help to raise awareness among students and allow them to address real-life problems facing the developing world. Indeed, professional training should encourage students to work across disciplines and develop capacities in communication, teamwork, creativity and resilience, as well as broaden their knowledge of the discipline [6]. It is also crucial that students work in relation to their own socio-technological and economic context. In particular, design education should systematically provide an understanding of an object as well as the invisible relationships connecting both client and designer’s worlds, the external environment and the biosphere [7] from an interdisciplinary perspective. Interdisciplinary activities in undergraduate design education demonstrate the rewards of integrating the structured and analytical mindset of an engineer with the intuitive thinking of a designer. Cross-fertilization between disciplines enhances learning and improves understanding of the contributions made by each participant, as well as an overall appreciation of concepts and ideas [8]. Scholarly collaboration is seen as a natural way of diversifying and building on students’ field of knowledge in addition to providing them with multiple viewpoints [9]. In this way, fostering collaboration between design students and students in public health (whose curriculum provides few opportunities to work with design) strengthens their training, provides context to their work and encourages the development of key skills such as creativity, entrepreneurship and communication [6].

2 Problem-Solving, Creativity and Innovation

Innovative thinking, where an individual's creative potential is maximized using certain tools and methods [10], is key to guiding and supporting scientific innovation. Indeed, creativity forms a building block of innovative thinking because it encourages the development of ideas that are both new and useful [11, 12]. Creativity is commonly understood as the result of a process where individuals develop ideas, solutions and even products that are original and of value [13]. In the context of product development, "The 'application' of creativity… is—what in industry usually is agreed upon as the origin of innovation—by large the determining factor for the survival of companies in the today's highly competitive environment" [14]. Therefore, creativity should be encouraged early on in teaching and learning.

When developing creative solutions, we rely on the same capacity to process information used when responding to everyday problems [15]. Design, which is seen as a form of problem solving, is natural and one of the most universal human activities [16]: "The [design] process starts by identifying needs and dissatisfaction with the current state of things, and acknowledging that something should be done to remedy the situation," requiring the acquisition, evaluation, production and transfer of knowledge [17]. Problem-solving from an interdisciplinary perspective enriches the design process. It allows for the exchange of diverse types of expert knowledge in service of a given project, thereby enhancing understanding and relevance. Interdisciplinary collaboration, while often generating hierarchies, has given way to new initiatives, tools and platforms that are horizontal and non-discriminatory, thereby allowing all participants to interact in the same capacity and with equal weight [18]. For example, Böhmer et al. [19] state that medical knowledge or know-how serves as a foundation for developing medical devices. In this scenario, however, interdisciplinary collaboration is a challenge. Product design and public health are set apart, divided by separate domains and spheres of knowledge. This ultimately hinders communication and exchange. Torrisi and Hall [20], basing their findings on an interdisciplinary research study, demonstrate that communication problems can actually drive design innovation if they are capitalized on during the initial stages of the interdisciplinary creative process.

3 Study Context (Region, Country)

In Latin America, and in particular Chile, health is viewed as a human right and the State is seen as its guarantor [1]. It is important to approach design by looking at the ways in which it impacts communities and populations. In many cases, individual circumstances such as susceptibility to natural disasters require a practical view of the object solution as a way of satisfying basic needs during post-emergency reconstruction [21]. It is therefore important to consider the complexity and multiple dimensions of human experience, particularly when assigning roles and evaluating disciplinary contributions in a project proposal [22]. This is an ongoing challenge in the professional and business world, since generic and vague iterations of design are seen as a dispensable task, easily replaceable by any actor within manufacturing companies [23]. It is challenging to respond to and resolve problems faced by communities if key actors are unable to transmit their knowledge. Approaching these issues from an interdisciplinary perspective opens up the possibility of directly involving the community in the design of products, thereby facilitating co-development which empowers residents and provides them with the tools to respond to everyday problems. During the collaborative process, multiple ways of representing an object support individual dialectical processes [24]. Here, design artifacts not only transmit a specific idea, but also serve as a means of negotiating limits, calling attention to discrepancies and finally opening the door to alternative perspectives [25]. This paper presents the preliminary results of an interdisciplinary design and health workshop. Both industrial design students and students in the field of public health worked together during a "Design Week" to develop products that responded to problems faced in the healthcare sector. Upon completion, students' participation in project tasks was evaluated.

4 Materials and Methods

In order to assess results of the "Design Week," a quantitative pre-experimental study was performed using a descriptive scope. This approach provided insight into changes in the work methodology in view of the small sample size and absence of a comparison group.

4.1 Participants

A total of 29 students enrolled in the workshop were evaluated, 21 of which were industrial design students and the remaining eight were students in the field of public health. Design students were enrolled in their second year of college at the Universidad del Bío-Bío, and public health students were enrolled in varying programs and levels (4 medical students, 1 nursing student, 1 kinesiology student and 1 medical technician) at the Universidad de Concepción.

4.2 Instruments

After the design week, students were evaluated using the following instruments:

– *Design Week Assessment Questionnaire*: A questionnaire made up of 30 questions following the Likert scale was used to evaluate the implementation of activities, lessons learned, group performance, the quality of the finished product and finally application of the three-step process. Each question had 7 possible responses (from 1 = Completely Agree to 7 = Completely disagree), Table 1. In addition, the questionnaire featured two open-ended questions prompting general feedback on the activity and any suggestions.

– *Semantic Differential for Evaluating the Finished Product*: A Semantic Differential was implemented using eight characteristics proposed by Oman et al. [26] in addition to two new characteristics for this particular study, all of which are pairs of antonyms (e.g. Original-Unoriginal). There are 21

Table 1 List of design week assessment questionnaire items

Items
1. Instructions were clear
2. Guidelines helped me navigate the activity
3. Expectations of the activity were clear
4. The activity was motivating
5. The activity as a whole provided me with insight into elements of product design
6. The activity helped to hone my creative side
7. The ability to work in an interdisciplinary fashion was motivating
8. Working in teams with students from other disciplines was easy
9. Working in teams with students from other disciplines was useful
10. The "Reality Check" activity was useful for developing the project
11. The "Reality Check" activity was motivating
12. The "Reality Check" activity helped me to better understand product design
13. "The Problem" activity was useful for developing the project
14. "The Problem" activity was motivating
15. "The Problem" activity helped me to better understand product design
16. The "We are all designers" activity was useful for developing the project
17. The "We are all designers" activity was motivating
18. The "We are all designers" activity helped me to better understand product design
19. The online forum and groups were useful for completing the activity
20. I found it easy to work with my team members
21. Work tasks were appropriately divided among all members of the group
22. All members of the group completed their tasks
23. There was sufficient time to carry out the activity
24. The product developed by my group was innovative
25. The product developed by my group provided a concrete solution
26. The product developed by my group was sufficiently completed
27. My team had sufficient information on the topic for developing a new product
28. My team had sufficient information on aspects of design for developing a new product
29. We searched for additional information on the topic when developing the product
30. We searched for additional information on aspects of design when developing the product

Author's own

intermediary characteristics which were used by students to describe their finished product.

Both questionnaires were developed by the research team and subject to review by a panel of experts. Moreover, a demographic study was carried out in order to identify the sex, age and career field of each participant.

4.3 Procedure

During the first week of the interdisciplinary design workshop, groups of four students were asked to design a product that responded to a pressing need in the public health sector. In order to do so, they were asked to apply a user-centred and participatory focus. For the first challenge, students chose to work on assisting patients with multiple injuries. Each group consisted of three student designers and one student in public health. Students were then given one week to develop an object-oriented solution, according to the following stages, Table 2: (1) "*Reality Check*": First, students were asked to participate in a role-playing situation involving patients with multiple injuries. This activity was developed by three nursing students and one kinesiology student (Fig. 1).

Relevant procedures, reasons behind these procedures and main challenges were discussed. Following this activity, students asked a series of questions in order to deepen their understanding of the situation: What is the role of the user? What steps does he or she follow when taking action? What resources are needed in order to do

Table 2 Instructions for the 1st challenge on design and health

Activity 1: Reality Check. In response to the following scenario, please formulate a problem which will guide your design process. (a) The topic is first-aid response in the public sector. (b) Three student nurses will present a set of procedures, their objectives and primary challenges, using role-playing and clinical simulation. (c) The goal is to develop a greater understanding of this activity while responding to the following questions: (1) What is the purpose sought by the user? (2) What steps does the user take in order to achieve this purpose? (3) What resources are utilized? (4) What are some things that help with the activity? How do they help? (5) What makes the activity more challenging? How does it make it more challenging? (6) What are some unintended consequences from this procedure? (7) What are some unintended benefits?
Activity 2: The Problem. Each group should outline the ideal procedure for the activity and identify any missing components in the present set of procedures. Along the same lines, please define the problems, needs and wishes that emerge from the difference between the two
Activity 3: We Are All Designers. Over the course of one week, each group should propose one product that allows them to meet this goal. The product should meet the following specifications: (1) A physical product, represented by sketches, (2) This object must respond to one or more problems, needs or desires previously identified in the activity, and these responses must be explicit, (3) It should be innovative, or in other words, different from what is traditionally used. This may take the shape of a completely new object or an already existing item that is reconfigured

Author's own

Fig. 1 Role-playing (*Source* Author's own)

Fig. 2 Design proposal: pneumatic splint for oxygen delivery to extremities by group no 5 (*Source* Hananias et al. 2016 [27])

so? (2) "*The Problem*": On the same day students began to identify problems or challenges arising from first aid care. They carried out interviews with a panel of experts (nurses, physiotherapists, industrial designers and psychologists) in order to gather key information which would assist with identifying and formulating the "problem" to be addressed, as well as key factors. In addition, they creatively explored potential solutions. (3) "*We are all designers*": During the first week groups were provided with working guidelines in order to develop a draft of their design proposal. At the same time, groups had access to a forum where a panel of experts and peers could respond to their questions and inquiries, Fig. 2.

Assessment
Descriptive statistical analysis was applied to data collected from both instruments.

5 Results

Results from the Design Week Assessment Questionnaire show that students positively evaluated the activity. A majority of students selected "Agree," followed by "Strongly Agree" and "Completely Agree" (39, 32 and 29% respectively). When consolidating responses into three equal categories (Agree, Neutral and Disagree), the *majority of responses are positive, thereby demonstrating an overall positive evaluation of the activity.* More specifically, we can see how a majority of students

"Agree" with the statements (5 and 6) that the activity helped to motivate participants and broaden their understanding of product design (35%). With regards to teamwork (statements 7, 8 and 9), the majority of students "Completely Agree" that working in interdisciplinary groups was both inspiring and useful (50 and 42% respectively). Nonetheless, 16% of students either "Disagreed" or "Strongly Disagreed" with the time allotted to complete the activity, while 4% remained "Neutral." With regards to the evaluation of each stage, the majority of participants "Completely Agree," "Strongly Agree" or simply "Agree" with statements 10, 11 and 12 that the "Reality Check" activity helped them to learn more about product design (62%). Twenty-seven percent of students remained "Neutral." Moreover, 92% of students found it useful and 81% found it inspiring. On statements regarding "The Problem" stage of the activity (13, 14 and 15), the majority of students (92%) agreed that it was useful for project development ("Completely Agree," "Strongly Agree" or "Agree"). A total of 73% of students found it motivating and agreed that it provided them with a better understanding of design. Regarding the final stage, "We are all designers," students agreed with statements 16, 17 and 18 ("Completely Agree," "Strongly Agree" or "Agree") in the following manner: 96% found that it was useful, 81% found it to be inspiring and 84% agreed that it provided them with a better understanding of design. Finally, with regards to Semantic Differential, characteristics of the product that were positively evaluated included "useful" (M = 5), "ordered" (M = 4), "functional" (M = 4) and "logical" (M = 4). Negative characteristics include the "invasive" nature of the product (M = −1) and the fact that they were "ugly" (M = −1). Student evaluations may reflect a number of issues: the context of the work, the functionalist-driven approach of the School of Design, students' own desire to create a pragmatic and easy-to-use object, or the push to create an innovative and coherent design solution in the time allotted (Fig. 3).

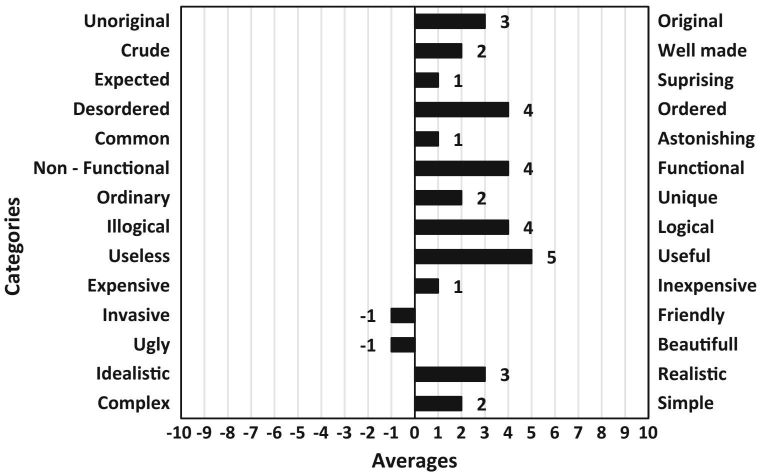

Fig. 3 Average student rating of their final products (*Source* Author's own based on Oman et al. 2013 [26])

6 Conclusions

Results show an overall positive (but not excellent) evaluation of the activity. On the one hand, it is clear that students were inspired by the activity and encouraged to broaden their knowledge. In particular, students had a favorable opinion of interdisciplinary teamwork, which, as mentioned above, may be useful in compensating for shortcomings specific to each discipline. It may also allow individuals to develop a more comprehensive view of certain phenomena, which is often inaccessible when addressed by isolated fields [4, 5]. On the other hand, students positively evaluated working across disciplines. This may be attributed to the fact that three of four health students were enrolled in the same program and the fourth student was enrolled in another university and program. Results show that it is not only possible but also beneficial to organize interdisciplinary activities with students from different programs and even different institutions. With regards to the activities, the first stage ("Reality Check") was seen as both inspiring and useful for the majority of students, helping to broaden their knowledge of product design. Nearly a fourth of students remained "Neutral," however, which may be attributed to design students' lack of knowledge of the public health sphere.

Students held a favorable opinion of the second stage: "The Problem," and they were motivated by the task of identifying differences between the current situation and an ideal outcome, although they received no previous formal training.

The third stage ("We are all designers") received the highest evaluation. Results show that the task of designing an innovative product that would respond to real needs in the public health sector ultimately motivated students and encouraged their learning process. However, the fact that it received a more positive evaluation than other stages shows how students prefer to focus their attention on the design stage rather than reflexive activities. Students may tend to gravitate towards "action" rather than the initial stages of evaluating and analyzing a situation. Study results may explain the Semantic Differential, whereby proposed products are mainly regarded as invasive, ugly and expected. In this way, we anticipate that students who concentrate on the final outcome will end up with a product that falls short of fundamental aspects that ensure its contribution to the field. Results may be attributed to a number of factors, such as the functionalist approach of the School of Design, the desire to create pragmatic and easy-to-use objects, or the pressure to develop an innovative and coherent product solution in the time given. For future initiatives, it will be essential to provide clear guidelines on work procedures, with specific information on the preparation, development and close of the activity in order to bring participants into sync. The short duration of this activity and participants' lack of prior experience provide insight into the innate abilities and attitudes of students—an excellent preliminary diagnostic tool. A more complex understanding of the present study may be achieved by involving students from different grade levels and, once there is a sufficient sample, carrying out an experimental study with comparison groups.

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Using Senior Design Project to Teach Design for Use of a Mechatronic Device

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Abstract Recent innovations have focused on the development of products which have embedded features such as sustainable energy power sources and intelligent controls which take into account energy efficiency and environmental variables that drive the total cost of the product ownership. The primary purpose of such efforts is to promote products that are more energy efficient and that are making smaller environmental footprint during their lifecycle. Lower cost, easy assembly and better manufacturability are some of the parameters that are part of the Design for Excellence (DfX) methodology. One of the most significant expenses that customers will face will occur during the use stage of the product lifecycle. This paper discusses the application of Design for Use (DfU) strategies on a conceptual design and prototype of a solar skimmer for a swimming pool. A group of senior students

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in mechanical engineering technology program completed this project as their requirement for graduation.

Keywords Design training and education · Design for use · Mechatronic systems

1 Introduction

Engineering education has the main objective of teaching students how to design components, assemblies, processes, software, and systems, and the understanding of the creative synthesis of new systems and components [1]. Hence, the culmination of their engineering education process at the undergraduate level in the U.S. colleges is the design work for the senior/capstone project. Design experience in these courses provide students with an experience that would prepare them for the work under tight deadlines and with given design constraints at their future workplace [2]. Another important component of this experience is to expose students to other disciplines so that they can work on multidisciplinary projects. For example students from Mechanical Engineering Technology major working on a project that includes elements from Electrical Engineering Technology and Computer Technology fields [3]. In such a case, students design, prototype and program mechatronic devices that require practice and attainment of a new set of skills such as the ones related to programming of microcontrollers, use of sensors, or estimating specific power requirements. Often these mechatronic systems have to comply with various environmental regulations and directives [4]. Mechanical engineering technology programs at different universities have added new courses related to the multidisciplinary aspects of engineering design such as Mechatronics, to prepare students majoring in Mechanical Engineering Technology to cooperate better with Electrical and Computer Engineers when working on a complex project [5].

2 Engineering and Engineering Technology Programs in US Institutions

There is approximately 200 ABET (Accreditation Board for Engineering and Technology) accredited engineering technology programs offered by higher education institutions in the U.S.A. Engineering technology programs also require four years to complete like the engineering programs however the emphasis is on the application. Students are encouraged to participate in internship positions and spend more time in labs designing and building working devices. Hence, senior design projects or capstone courses are an integral part of their experience.

3 Senior Design Projects in Engineering Technology Department at Old Dominion University

The project presented in this paper was a senior design project in the Mechanical Engineering Technology program. Thi program is one of the three programs within the Department of Engineering Technology. Every student enrolled in this program is required to take a set of two sequential courses in their senior year to complete the senior project. The first one of these two courses is MET 434, Introduction to Senior Design and the second one is the MET 435 W, Senior Design Project. The key requirement for students during the first course is to come up with the proposal idea for the project showcasing what they have learned throughout their four years of undergraduate studies. Some students choose to design and create a prototype of a new product, others to optimize an existing engineering solution, and some do an optimization project for an engineering problem. Introduction to Senior Design is a one credit course that includes one hour of instruction per week. Project requirements, among other such as ethics, writing, standardization, professional development, citation includes a viewpoint related to the various design issues including environmental friendly designs and materials and sustainability. The second course, Senior Design Project is the three credit course that includes three hours of instruction or laboratory work per week for fifteen to sixteen weeks, and its objective is the actual implementation of the project. This project-based course is an independent study in which students have to find an relevant research/design topic, brainstorm about the possible solutions, choose design, optimize it, build a prototype, simulation or engineering solution and present it to the departmental committee and their peers. They also have to write a final report and have an oral presentation of their design and prototype in front of their peers and departmental faculty committee. The department and the engineering college offer internal competitions for student senior design teams which are usually multidisciplinary and involve groups of students from different engineering areas, such as Society of Automotive Engineers Mini Baja, Formula One. With limited funding available, many of the students are interested in designing and building cost-efficient prototypes. Lately, more and more students are taking into consideration the total product ownership and more sustainable design practices one example being the use of the solar panel.

4 Design for Use Design Methodology

Today's design methods are adapting to reflect changes in environmental regulations and directives. Engineering design process no longer focuses solely on a cost of the final product, but also on the cost implications related to the manufacturing, the life-cycle of the product, and their use and disposal to the environment at the end of their lifecycle [6]. Design for Environment (DfE) methodology includes

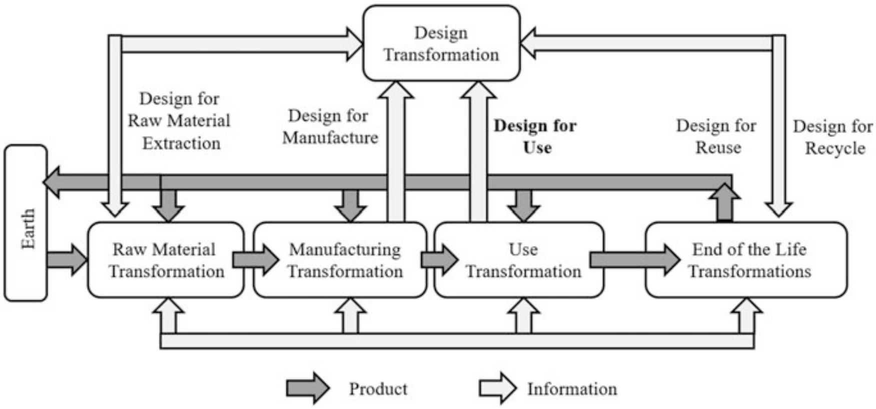


Fig. 1 Design for use relation to the product and information flow [9]

design considerations related to the product's safety, environmentally non-compliant materials, service life, recyclability, energy use, waste content, and disposal option [7, 8]. Another industry trend in many countries has become the development of more environmentally superior and compliant products [9]. One of the lifecycle information loops is Design for Use (DfU) that focuses on the cost associated with the use phase of the product, as shown in Fig. 1. Design for Use methodology is best known in the automotive industry since vehicle design requires adaptation to the higher energy efficiency requirements each year [10].

5 Design of Solar Powered Autonomous Pool Skimmer

Several patents related to the solar powered autonomous pool skimmers are available [11–15]. They all include some principal components for propulsion, for collision avoidance, and for storage and collection of the debris. Debris can be in the form of leaves, plants, dirt, algae, insects, and so on [14]. Pool debris usually falls to the bottom of the pool and high energy consumption devices are used for its extraction [11]. New designs are focusing on removing the debris before it hits the floor, from the pool surface. Skimming debris from the surface uses less energy than retrieving debris from the floor since the pressure at the surface is smaller than the one at the bottom of the pool [12]. This recent trend has led to the application of solar cell arrays to pool skimmers, as they do not require high velocities, and they can operate with the power retrieved from solar sources [11, 13]. Other issues that a skimmer design faces are the use of nets which may miss the collection of some debris, the use of large amounts of energy for the operation of main filters, and the threatened approach in the design, with cords across the swimming pool, and poor collision avoidance [11]. For the "Solar Powered Autonomous Skimmer" senior project presented in this paper, there were originally three students the team [16]. They developed solutions for all the technical design constraints to which they added the available budget constraint. The inspiration for this prototype was the iRobot Roomba robot used for floor cleaning and the Airboat which is a lightweight boat propelled across the water surface by a fan. The main objective of the proposed design was to create a prototype of working pool skimmer that would be powered by the solar cells. Student team came up with this idea because of the majority of current solutions use a lot of electrical energy, and they do not have the option to recharge through the solar cells. Location of Old Dominion University is in the southern part of the United States where is plenty of solar energy during the times that the pools are usually being used through the year. They got inspiration from the autonomous vacuum cleaners for the control methodology. They came up with the idea to have a skimmer that would charge itself while the owner is not using the pool and to clean up the pool autonomously when needed. Due to the budget constraints, students wanted to create a pool skimmer with affordable and easy to find materials that can be easily purchased and build if necessary by someone who has project plans [16].

The main parts of the skimmer are a structural frame, platform, propulsion subsystem, and the control system. In this design, a battery powers the fan that drives the propulsion system of the skimmer. Solar panels are added to the design to charge the battery. The frame that holds other components consists of pipes, fittings, elbows, end caps, primer, and glue. The power subsystem consists of solar panel, battery, sensors, Arduino board, fan, relays, and voltage regulator. Materials in the platform are plywood, basswood, glue, and paint. The structural frame is presented in Fig. 2 and contains small CPVC pipes. The material of these pipes is lightweight, strong, easy to configure into various shapes, and meets the criteria of low cost and availability. CPVC pipes are placed inside the foam to help the skimmer float as well as to protect the liner or sides of the pool from being damaged in case the skimmer hits a wall.

For floating purposes, a pool noodle met the cost and availability criteria even though there are many industrial foams available from hardware catalogs. The design also includes a net for collecting the debris from the surface of the water.

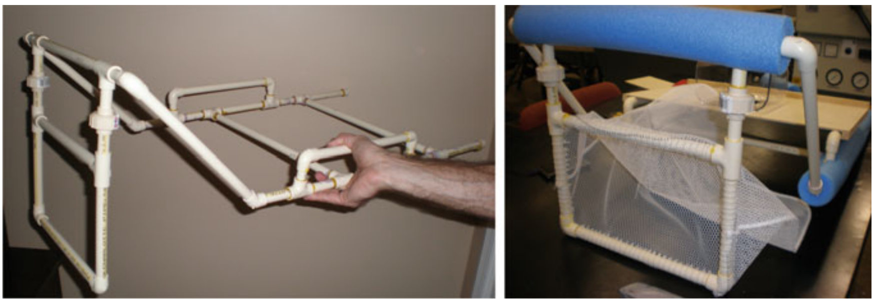


Fig. 2 Structural frame and a net of pool skimmer [16]

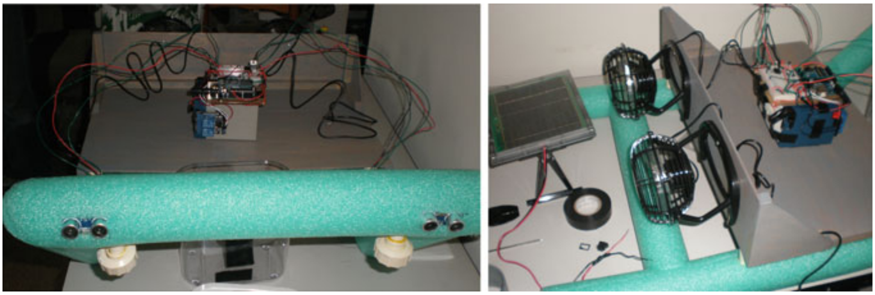


Fig. 3 Ultrasonic sensors in autonomous pool skimmer [16]

In the final design, an attachment point for the net on the pool skimmer was made similar to the commercial net that attaches to the end of a manual pool skimming pole. The net can be removed for dumping, cleaning, and replacement in the same way as for a standard pole skimmer. During the prototyping, the initial design included one fan that was attached to a stepper motor. The motor would change the direction of the fan resulting in the turning of the pool skimmer. The electric circuitry of the skimmer includes an 8 and a 5 V regulators, relays, and diodes. It also includes a USB port with a maximum rating of 5 V. Arduino microcontroller controls a parallel pair of ultrasonic sensors. The ultrasonic sensors need a 5 V input and a working current of 15 mA. Because the Arduino has a 40 mA output on each pin, there was enough current to run both ultrasonic sensors as shown in Fig. 3.

The use of a second fan would alleviate the need for a mechanical steering mechanism. Either fan can control the steering by turning off after a relay sensed an obstruction. A single data wire connected each relay and the fans. The idea was that each ultrasonic sensor would control the dual relay which further controls the fans. Once everything was tested and assembled using precut electrical wires, students custom cut and soldered all the wires to allow for better connections and a more compact design.

The entire compact assembly was in the airtight container which sits on top of a wooden platform. The solar panel was on the top of the container, and it faces upward to maximize the amount of sunlight it could collect. The fans were mounted to the back of the platform, as shown in Fig. 4.

5.1 Solar Powered Pool Skimmer Testing

A variety of tests were performed throughout the project design to test the performance of the skimmer. One of the first tests performed was a bathtub test during the conceptual design phase. This experiment was conducted to estimate the maximum weight that the USB fan could push and to determine the best mounting

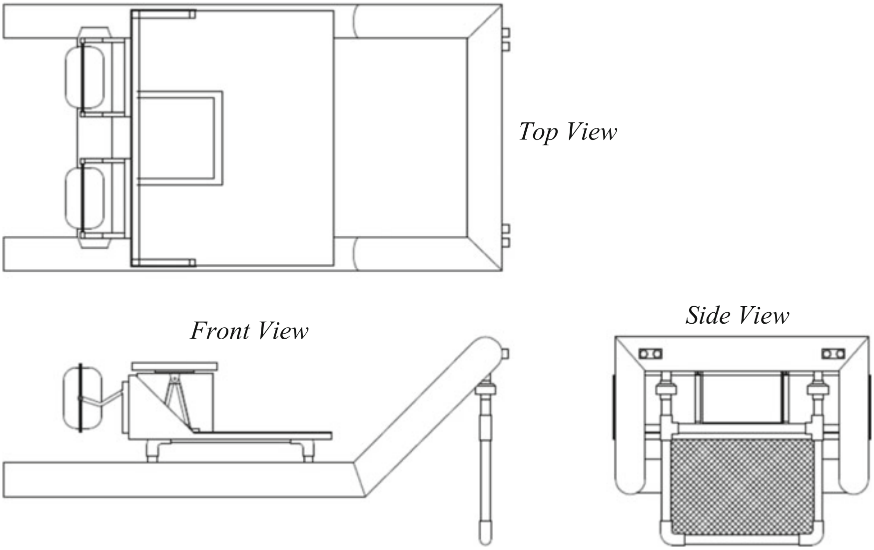
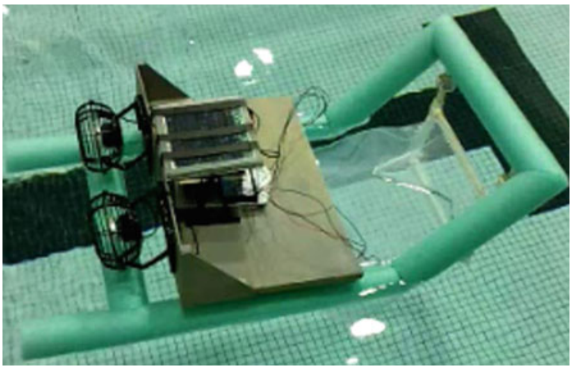


Fig. 4 Solar-powered autonomous pool skimmer CAD model [16]

configuration and the thrust capacity for one fan. After trying various configurations of the back mount, a straight configuration proved to be the best solution for the final design of the autonomous pool skimmer. This design provided the highest speed and a straight path. Figure 6 shows a set of four tests performed and demonstrates the relationship between the weight carried and the time necessary to move the weight. The plotted data of the four successful tests revealed that Test 4 was the optimal design regarding the shortest time/fastest speed achieved by the container. The data also show that 3 lb is the optimal weight for the design. While the plotted data demonstrates that the empty container was the quickest, it is not practical to use this as the design ballast load. The design fails to perform for weights of more than 3 lbs (Figs. 5 and 6).

Fig. 5 Pool test of solar powered autonomous pool skimmer [16]



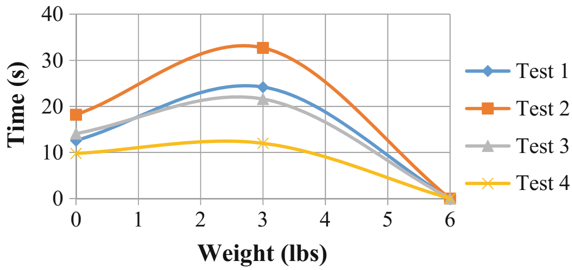


Fig. 6 Bathtub tests summary

5.2 *Venturi Experiment*

One of the requirements for the senior design project design validation was to develop and conduct all necessary experiments. For that purpose, students conducted Venturi experiment to validate and measure the real air flow that comes from the fan by using the Bernoulli balance to determine the actual flow and pressure difference. In this way, students measured the actual energy efficiency of the fan, another important factor for more sustainable designs. Manometers measured upstream and downstream pressure. The difference in pressures was then applied to the equation to determine the actual flow rate [17]. By placing the fan inside the Venturi experimentation setup system, students were able to take measurements on the initial burst of the fan. The data read out was 0.023 in H_2O and the leveled out steady state measurement was 0.005 in H_2O. The RPM reading was tested and compare to the manufacturer's rating. Manufacturer specification gave 2400 RPM.

$$Tube\,Diameter, D_T = 5.125\,\text{in.}\left(\frac{1\,\text{ft}}{12\,\text{in.}}\right) = 0.4271\,\text{ft} \tag{1}$$

$$Venturi\,Diameter, D_V = 2.562\,\text{in.}\left(\frac{1\,\text{ft}}{12\,\text{in.}}\right) = 0.2135\,\text{ft} \tag{2}$$

$$Venturi\,Area, A_V = \frac{\pi(0.2135\,\text{ft})^2}{4} = 0.0358\,\text{ft}^2 \tag{3}$$

$$\begin{aligned} \gamma_{air} &= 7.353\ \text{lb}/\text{ft}^3 \\ \gamma_{manometer\,fluid\,(water)} &= 62.22\ \text{lb}/\text{ft}^3 \end{aligned} \tag{4}$$

$$Q = C_V A_V \sqrt{\frac{2gh_V\left[\frac{\gamma_m}{\gamma_{air}} - 1\right]}{1 - \left(\frac{D_V}{D_T}\right)^4}} \tag{5}$$

$$
\begin{aligned}
\textit{Flow Rate},\ Q\ (\textit{Initial Burst of a single fan}) &= (0.95)\left(0.0358\,\mathrm{ft}^2\right)\left(\frac{60\,\mathrm{s}}{1\,\mathrm{min}}\right) \\
&= \sqrt{\frac{2\left(32.2\,\mathrm{ft/s^2}\right)\left(0.023\,\mathrm{in.}\left(\frac{1\,\mathrm{ft}}{12\,\mathrm{in.}}\right)\right)\left[\frac{62.22\,\mathrm{lb/ft^3}}{7.353\,\mathrm{lb/f^3}}-1\right]}{1-\left[\frac{0.2135\,\mathrm{ft}}{0.4271\,\mathrm{ft}}\right]^4}} \\
&= 2.023\,\mathrm{ft^3/min}
\end{aligned}
\tag{6}
$$

$$
\begin{aligned}
\textit{Flow Rate}, Q(\textit{Steady Run of a single fan}) &= (0.95)\left(0.0358\,\mathrm{ft}^2\right)\left(\frac{60\,\mathrm{s}}{1\,\mathrm{min}}\right) \\
&= \sqrt{\frac{2\left(32.2\,\mathrm{ft/s^2}\right)\left(0.004\,\mathrm{in.}\left(\frac{1\,\mathrm{ft}}{12\,\mathrm{in.}}\right)\right)\left[\frac{62.22\,\mathrm{lb/ft^3}}{7.353\,\mathrm{lb/ft^3}}-1\right]}{1-\left[\frac{0.2135\,\mathrm{ft}}{0.4271\,\mathrm{ft}}\right]^4}} \\
&= 0.843\,\mathrm{ft^3/min}
\end{aligned}
\tag{7}
$$

However, tested value showed that the fan has a velocity of 2131 revolutions per minute.

$$\textit{Actual RPM}, RPM_{Actual} = 2131\ \frac{\mathrm{rev}}{\mathrm{min}} \tag{8}$$

$$\textit{Experimental RPM}, RPM_{Experimental} = 2400\ \frac{\mathrm{rev}}{\mathrm{min}} \tag{9}$$

The efficiency of the fan is smaller by 12.62%. Hence, the design had to accommodate this difference in the design specifications of the purchased component.

$$
\begin{aligned}
\textit{Percent Difference} &= \left|\frac{RPM_{Experimental} - RPM_{Actual}}{RPM_{Actual}}\right| \times 100\% \\
&= \left|\frac{2400-2131}{2131}\right| \times 100\% \\
&= 12.62\%
\end{aligned}
\tag{10}
$$

5.3 Testing the Final Design

The water test of the design was positive, as the skimmer floated and balanced in the water. The placement of the fans and the electrical assembly perfectly counterbalanced the nose and the net of the skimmer. When the skimmer was turned on and left alone, it moved through the water at a slow but steady pace. When the skimmer approached a wall, the sensors detected the wall and turned off the fans appropriately. The team thought that the net was causing too much drag and that the skimmer could move faster without the net. A second test was without the net attached, and the results showed that the skimmer did move at a much faster pace than in the previous case. Some final design modifications were done to position the sensors better as they were both placed in front initially and it was difficult correctly turn off the appropriate fan. The final modification of the design was to notch holes behind the fans such that more air could be pulled and the skimmer could move faster. The final test performed was the full-size pool test, and the performance of the skimmer was as expected.

6 Conclusions

This paper presents a design example that integrates the reduced cost of a product during its lifecycle and operation with the use of renewable energy sources and considers the Design for Use as a methodology. As most of the power consumption occurs during the use phase, the power supply of the product was an essential part of the design considerations. The solar panels are used in this product for charging the battery. The pool skimmer prototype in the project is intended to operate for extended periods of time, so power efficiency and environmentally friendly solutions for recharging the battery were the primary drivers for the design. The student project presented in this paper is one example of embedding sustainable design practices and mechatronics design methodology into engineering design. This senior design project provided an experience that students will encounter in their workplace in future. Embedding this type of project in their undergraduate curriculum ultimately trains them to be a better steward of the environment.

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Design Thinking and Creative Problem Solving for Undergraduate Engineering Education in India: The Need and Relevance

Tigmanshu Bhatnagar and Petra Badke-Schaub

Abstract A way to spark design, creativity and innovation culture in the country is by encouraging Design Thinking and Creative Problem Solving in the vast spread of technical educational institutes in India. Facilitating them in engineering education would benefit students by providing them a structure to think creatively and meaningfully in their education and future profession. At the same time, it would bring the much-needed awareness about design's deeper notion of being a systematic and creative problem solving approach among engineering students. This would increase the value of design in the community of engineers. A study to evaluate the need and relevance of design thinking and creative problem solving from the perspective of engineering students was conducted in the name of a 'pop-up class' for one week, without any credit incentives at the Indian Institute of Technology, Delhi (IITD). 30 3rd year Bachelor students from various technical fields (chemical, mechanical, civil, production engineering, textile, electrical engineering and engineering physics) participated in the study. They were introduced to the topic via a mix of theoretical lectures, case discussions and practical workshops. The workshop had been evaluated by the students with a questionnaire at the end of the study and subsequently analyzed. All respondents answered that Design Thinking and Creative Problem Solving are relevant for their education. 90% responded positively to the suggestion of introducing such a course in their education stating that it's important for engineers to know how to solve real world problems in a meaningful way, and by this to drive innovation. Although most students agreed that it should become a compulsory course, they feared for its value, when it would become grade oriented like other courses.

Keywords Design thinking · Creative problem solving · Undergraduate engineering education

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1 Introduction

According to the Confederation of Indian Industry report, 'Design in India 2011' [1] there is a common sentiment within the design industry that Indian design graduates are not well trained/educated. They do not possess competencies required by the industry. The practitioners feel a disconnection between the syllabi and prevalent design trends. On top of that many universities in India do not realize design as a discipline requiring specific didactical support or underpinning. Most post-graduate design programs manifest themselves as an add-on to engineering, arts or architecture foundations, rather than being a complement to design education. A limited availability of qualified and well-trained design staff is another factor that causes a major hindrance in the path of well-trained design graduates. As a result, modern education has been inefficient to turn talented creative students into world-class designers. Thus a major need is felt for a strong design education intervention. In early 2014, directors of the Centrally Funded Institutions, important people from the design community in India and members of the Ministry of Human Resource Development of the Government of India conducted a session discussing the future of design education in India. As a result, a manifesto for the future of design education in India was formulated. It elaborated majorly on the goals and objectives for the centrally funded institutes of the country for an overreaching framework for design education to steer education and research towards social goals and economic aspirations. One of the manifesto's key focuses was to develop a design spine in engineering education [2]. It's an interesting offbeat notion to use design as an integrating discipline in engineering. The assumption being that the main characteristic of design such as design thinking and creativity could lead to a new goal in the education which is teaching students to think creatively, empathically and innovate with a high technical sense leading to meaningful value enhancement and overall growth. From another perspective, it makes sense to utilize the omnipresent promise of world-class engineering education across the country as a channel for the development of education in a designerly manner.

Not just in India, but researchers in education and industry leaders across the world have raised concerns about the future of engineering education. In May 2013, the American Society of Engineering Education hosted a workshop that brought together representatives of industry and academia in an intensive exploration of the knowledge, skills, and abilities needed in engineering today and in the coming years. The experts identified the core competencies that will remain key, but added an array of skills and professional qualities such as programming, systems thinking and innovative thinking with an impetus on the notion of design thinking as one of most often named competencies that will help students to cope with the complexity and dynamic developments in this rapid growing field [3].

2 Design Thinking and Creative Problem Solving

2.1 Design Thinking

There has been explicit description of the design and development process by Pugh based in his 'Total Design' model [16], which explains how designers approach and act to problems. Design thinking as a reflection on how designers builds knowledge and thinks is majorly based out of work of Cross and that of his colleagues from 1982–2000. This has been compiled under the title of 'Designerly ways of knowing' [17]. It reflects on drawing on design research to show Design as having its own intellectual and practical culture as a basis for education, and contrasting it with cultures of Science and Arts and Humanities. This is based on the idea that "There are things to know, ways of knowing them and ways of finding out about them that are specific to the design area." These are different ideas of approaching the term design thinking. Design thinking is established as a new business-socio-techno paradigm through publications by Brown [5]. The main focus is essentially not much different than all the well-known approaches and models of problem solving processes. Also, the emphasis on the three main focus points of design thinking (user centeredness, ideation and prototyping) is not essentially new but the way Brown emphasizes the need for the designer to be the person who has to take the lead can be seen as paradigm shift in the societal view on the designer's role in the product development process [6]. Like in any other problem solving process, needs and dissatisfaction with the current state combined with a determination that some action must be taken to solve the problem is the start of the design thinking process. Then, the ideation process shall heavily rely on mock-ups (in order to encounter failures often but early in the process when it is still affordable). This requires a person or a team to think and act both creatively and rationally to bring about a solution. The designer has to then juxtapose information from multiple dimensions (generally user centric, technological, business and environment), depending on the problem, to think of holistic solutions [4]. The approach is structured by the means of a process, which effectively enables people to understand the problem from the perspective of their users, ideate creatively, analyze logically, prototype and build solutions and evaluate them through stakeholders [5]. Such an approach is typically useful for complex open-ended problems, which are generally ill structured with changing requirements, leading to lack of a visionary solution. Not surprisingly, many scientists and professionals have been working and acting as design thinkers throughout their career, albeit often not being aware of or recognizing that they are performing design thinking.

However, over the last years, design thinking has been used and described elaborately and differently across literature. The term has been used to express a variety of notions. This has essentially exploded the complexity of understanding and defining design thinking. Hence, it becomes imperative to adopt or define the definition of design thinking which will be utilized for this study. Hence, design thinking has been adopted from [5, 7] and can be elaborated through the three following concepts.

1. Design thinking establishes itself on the understanding of two principles of thought: Divergent Thinking and Integrative Thinking [5]. Divergent thinking is a cognitive process used to generate creative ideas by exploring many possible solutions. Divergent thinking typically occurs in a spontaneous, free-flowing, 'non-linear' manner, such that many ideas are generated in an emergent cognitive fashion. Many possible solutions are explored in a short amount of time, and unexpected connections are drawn [8]. At the same time, complex problems require the integration of multiple domain knowledge that cannot be solved by analytical thinking alone. The goal of analytical thinking, which has been the main idea behind engineering education, is defined as the production of consistent replicable outcomes that can be proven through inductive and deductive reasoning. The other extreme is intuitive thinking, which essentially is knowing-without-reasoning. To bridge this fundamental gap, Martin [9] proposed an integration of analytical and intuitive thinking and terms this as integrative thinking. The proposed mindset is to allow for generative reasoning by integrating exploitation with exploration, analysis and intuition.
2. Brown [5] defines design thinking as a human-centered approach to innovation that draws from the designer's toolkit, thinking techniques to integrate the needs of people, possibilities of technology and requirements for business success. This is a manner to depict the central, multi-faceted mental framework required for design thinking.
3. Design thinking typically works in a systematic, analytic and creative process that engages a person in opportunities to experiment, create and physically build models and solutions, gather feedback, and enhance solutions.

These three notions together define design thinking at three levels. This first is at a cognitive level, which describes the manner of thinking a design thinker has to adopt. The second level reflects their mindset, which needs to be open to access the relevant information from multiple sources and the third is at the level of its implementation and actions, which a multidimensional team or even an individual can perform.

2.2 Creative Problem Solving

Creativity is a phenomenon whereby something new and valuable is formed. The created item may be intangible (such as an idea, a scientific theory, a musical composition or a joke) or an original physical object (such as an invention, a literary work or a painting). In essence, it's a mental ability to transcend traditional ideas and to create new ideas and solutions. Creative experts and educationalists like De Bono [10], Buzan [11] over the years have pictured creativity as process of

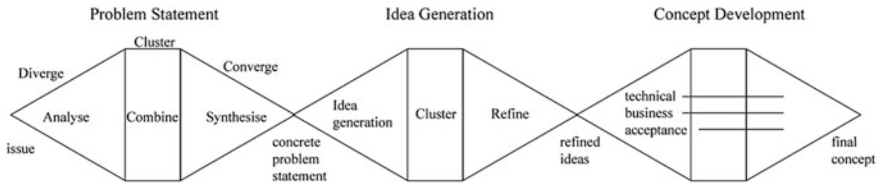

Fig. 1 The triple diamond creative process as proposed by Buijs [14]

thought and action, which can be learnt and facilitated. There are well-developed and documented models for creative problem solving from Popova [12], Osborn [13]. One of the more recent and practical models for creative problem solving is the 'Triple Diamond Creative Process', developed by Buijs [14] (Fig. 1).

A creative diamond is a visual representation of the building block of a creative exercise which involves the processes of diverging, clustering/categorizing and converging. In the triple diamond creative process, there are three such diamonds dissecting the entire process into the three parts of problem definition, idea generation and concept development, each having the three sub layers of diverging, clustering and converging. The structure in the process helps individuals and teams to work out complex problems creatively but in a systematical way.

3 Student's Perceptions and Reactions

The present engineering education setting majorly produces I-shaped graduates, or students with deep disciplinary knowledge. T-shaped professionals are characterized by their deep disciplinary knowledge in at least one area, an understanding of systems, and their ability to function as "adaptive innovators" and cross the boundaries between disciplines. Upon graduation, students should be able to handle information from multiple sources, contribute innovatively to organizational practices and communicate with an understanding across social, cultural, economic and scientific disciplines, eventually being more productive in work and results and hence, successful in their domain. From a broader perspective, in an effort to effect positive global change, T shaped mentality is essential. Practicing design thinking builds the groundwork for such a mentality, as the process itself deals with knowledge assimilation and utilization of that knowledge from multiple dimensions, oriented towards an exploration for the best solutions to a complex problem.

To foster this mentality, problem solving as a core engineering skill should be cultivated throughout the curriculum. Academia should provide more open-ended questions as in the real world and show that there isn't always a "right" answer, thus encouraging creativity and broad, open-minded thinking, allowing students to identify the real problem and figure out possible avenues to solve it.

Design thinking transcends design from being a skill to a process of cognition, thought and action, which can be utilized to solve complex open-ended problems. It is hypothesized in this research that the introduction and adaptation of design thinking in engineering education would benefit the students by facilitating them to think creatively and innovatively in their education and future profession in a systematic fashion. Teaching design thinking and creativity in a university setting suggests that students might become creatively productive in meaningful ways. Teaching with a purpose of facilitating creativity would also help students learn more about their own creative abilities, and attain greater personal and professional confidence, success and satisfaction through creative efforts [15]. An overarching speculation is that this intervention could lead to a trickledown effect for the awareness about design's deeper notion, which would help increase the overall value of design in the community of engineers.

3.1 Research Questions

A so-called 'crash course' was conducted at the Indian Institute of Technology, Delhi. The institute is one of the two educational institutes in India, which have been listed in Quacquarelli Symond's (QS) list of top 200 universities globally in 2015. It is considered to be one of the most prestigious schools of engineering in India.

The scope of this research was to find an indication to the following questions:

1. What is the perceived relevance of design thinking and creative problem solving in engineering education?
2. What are the implications of a combined teaching concept of design thinking and creative problem solving on the problem solving process of engineering students?

With answers to these two questions, the need for creating such an intervention and the perceived relevance from the perspective of students can be judged.

3.2 Participants

99 third year bachelor (3 of the 4 bachelor years in engineering education) students initially showed interest to attend the course as a response to an online poster via the university mail server. This selection was based upon two important reasons. First that by the third year, students are well established in the engineering education setting and second, they are still motivated to learn new things. It is important to note here that no academic credits were being offered. As a shortlisting process to obtain a manageable number of participants, students were made to identify a

practical daily life problem, a pressing need or an irritating issue that just had to be solved and provide a justification for the same. Based on their response, 30 students were shortlisted out of which 21 students completed the course. The reasons for dropping the course as enquired were due to illnesses, odd timings of the class and inability to understand the point of doing it. Students were from diverse technical disciplines, which included chemical, mechanical, civil, production engineering, textile, electrical engineering and engineering physics.

3.3 Method

The course took place in the vicinity of the campus during after school hours for a week. The planned time for engagement was estimated to be 10 h; i.e. 2 h every day for 5 working days. However, practically the course went for over 15 h of engagement due to the enthusiasm and commitment of the students. The workshop was a mixture combined by theoretical lectures, case discussions and practical workshops, what can be seen in Table 1.

Table 1 The goals, content and course of action for each day of the workshop

Theme for the five days	What was intended?	What was done?
Day 1: Introduction—testing the playground	To make them curious, to listen to first reactions of the students in regard to the learning objectives and observe their present problem solving skills, their approach and teamwork	1. Introduction to the content and the learning objectives from the course 2. An icebreaker game before beginning the problem-solving phase 3. For the problem solving, the class was divided in 5 groups of 5–6 participants in each. A selection of problems which they provided were rephrased briefed and provided with the background information (media articles.) sufficient enough to understand the problem 4. They were given around 100 min to come up with solutions to the problem and present them to the entire class 5. During this process the design behavior of the students as well as the problem solving process including the final solutions has been observed

(continued)

Table 1 (continued)

Theme for the five days	What was intended?	What was done?
Day 2: Approach 1—design thinking	To introduce the notion of design thinking, establish a reason for them to be present in the class. Make them aware about how it's being utilized in different scenarios across the world and in different disciplines such as engineering and innovation and what can we extrapolate from that	1. An interactive lecture about Design thinking 2. Case studies and discussions around the practical examples where DT worked and did not work, Apple, Ducati, Google glass, Air BnB (covering all engineering & entrepreneurial bases) 3. Discussion of how they might have been using DT in any of their projects (to make them identify the process in their language)
Day 3: Approach 2—creativity and CPS	To break the notion that people are born either being creative or not and inculcate the fact that creativity can be learnt and taught. To introduce the creative problem solving process and how to address the solution finding in a structured way—for example with idea generation techniques	1. A very interactive lecture on creative thinking with provocative questions 2. Methodological approaches to creativity and practicing some idea generation techniques 3. A theoretical intro to the triple diamond creative problem solving process was also given to orient them with the structure of the process
Day 4: Methodological support—a guided process	In this phase the intention was to support and practically guide students in the three phases of the CPS diamond. Thus they were taught different methods for generating ideas. In addition to this process dimension the content was practically always related to keep the three dimensions alive during designing, to balance human needs, business viability and technical usability in the process	1. Facilitated groups with the same problem through the processes using various idea generation techniques 2. Helped students to evaluate the solutions based on evaluation techniques best suited for the kind of ideas they had 3. Insisted on solutions to have the three dimensions of human needs, technical feasibility and business value to a very basic level
Day 5: Practice—application of the newfound knowledge	The last phase was intended as a kind of intervention check: Did the students understand the new introduced concept, did they develop a different mindset to in a more creative, efficient and proactive way?	1. Identifying and narrowing down the complex problem to one rephrased problem to solve, follow the triple diamond process and the design thinking approach to solve the issue and have a techno centric solution, not socio-political 2. It was converted in a mini competition to instigate a sense of challenge in the group 3. At the end they had to present three best solutions to a jury of professors and an award was given to the best, most comprehensive, feasible, viable and innovative ideas

The research questions were answered on the basis of silent observations made during the course and a questionnaire, which was filled after the course. All the methods of enquiry are subjective and provide qualitative data. In other words, the results are subjective perceptions of the students, which may include many complex factors such as the environment, intrinsic motivations, attitudes, information delivery, personality of the facilitator etc. Hence, the results are to be considered indicative more than conclusive. Observations were mainly made during the first and the last day. They were made typically on two grounds, actions and results. 'Actions' involved observations made on teamwork, attitudes and the process. 'Results' observed their final outcomes and presentations. This was done to see if students are able to bring about a change in the final solutions based on a change in their way of working and thinking.

Three days after the end of the course, a questionnaire (Appendix 1) was provided online. On the scale of 1–10, student's perceived relevance and benefits and improvements in their approach to problems were enquired. The effect on the quality and quantity of ideas and final solutions was also questioned. Importantly, the reasons for their perceptions were enquired in the pretext of a question if they would like to have this as a course in the curriculum and why? The answer gave an indication as to the qualitative reasons, from a student's perspective to introduce design thinking and creativity in engineering. These justifications are one of the most crucial academic findings from the research.

4 Results

Based on the observations of the students` behavior during the problem solving the following most interesting situations in the duration of the workshops are as follows:

1. On the first day, there was significant confusion to understand the design exercises. Open-ended problems posed a major challenge to the thinking and acting of the students. Many got stuck at multiple stages in the exercise as they had a haphazard, uncontrolled and unstructured process, in which some eventually lost interest, and a majority struggled. This resulted in generic ideas, which were slightly detailed technically in the given time. However by the end, this changed significantly. In the last session, students approached the problem better, they were more confident, structured and involved in the process. This phenomenon was observed and is evident from one of the participant's response:

> According to me, it really enhanced my problem solving skills. I already think that I am bit creative but this course let me organize my ideas well and made me to think in a very structured way. Thanks!

2. As was expected, majority of the students were good analytical thinkers. As a result, even the divergent process of the exercise was broken down to an analysis problem and then, their approach grew. For example, the stage of developing ideas for the design problem was broken into keywords, which were subsequently, separately analyzed and then combined to build up a solution.
3. In the initial sessions, certain ideas were analyzed deeply from a technical perspective and their feasibility point of view. It was interesting to observe that by the last session, analysis was observed from the dimension of what users would have to do for the innovation and how it will work for them in their context.
4. Although students were not experienced in working in teams, teamwork was evident and naturally occurring. As in teams, some students were being too defensive to get their ideas and some preferred thinking alone. This attitude changed over the days and by the last engagement, teamwork was better and the quality of the results improved.

The most important results of the questionnaire are listed in Table 2. The questionnaire asked the participants to compare their first day of experience with the final day. The critical questions have been listed along with the average score of responses and the interpretation of the results. They are complimented by the comments of students regarding the course and its induction into the curriculum.

The question whether the students would like this workshop as a course in their education, was mainly positively answered. In the following some of their responses are quoted:

> This could be a course in which students can put their whole effort in solving problems in their daily life and come up with creative solutions. While the other courses just teach us new things. This course can bring out the new things with in us. So yeah, it would be great!

> Design is an integral part of any engineering stream and most of us have no exposure to creative designing techniques. We do have Design Courses at present but they have different objectives. It would be nice to have a design course that focuses more on how we arrived at any idea instead focusing only on what idea we arrived on, which is the case with the present design courses.

> From design thinking we learn identifying and stating problem clearly, process of getting a number of solutions and choosing out a better and refined solution from them. These are the basis of solving any real time problem. So, according to me, Design thinking should be a course, not only for the engineering students as well as every students.

> All courses here will eventually become grade oriented, and I don't think we can teach such things in a regular classroom. Something out of the box or motivation needs to be given for starting such a course, unless people are interested. If it is going to be a course, it should be non-graded, innovation oriented and should have regular presentations. Small sessions are effective than semester long courses, obviously like this one.

The final remark is a major concern for such design-oriented courses with active engagement of students. The grading criteria have to be adapted for such courses as conventional grading schemes may not be well suited.

Table 2 Selected results of the questionnaire

Question	Average score (1…10)	Interpretation of the results and comments from the students
With respect to your engineering studies, how relevant do you think is design thinking? (0 being not relevant and 10 being very relevant)	8.21	Students majorly feel that the notion of design thinking, as a part of the coursework is relevant but not extremely relevant. None believe that its not relevant. These results might be a reflection of the short duration of engagement and hence, a majority responded positely but not completely affirmative "*Design Thinking as a process is an involving process and maybe 5 days was too short a time also such unique initiative when tested requires a longer duration to assess the progress and improvise the methodology.*"
With respect to your engineering studies, how relevant do you think is creative problem solving? (0 being not relevant and 10 being very relevant	8.69	On an average, students felt that the relevance of creative problem solving is slightly more than the design thinking. This result suggests that process might be able to fill the gap of approaching complex, illstructured problems in the education system "*In class we study fundamental of science and engineering, but courses like this will help to focus on real life problem. After this workshop, I found that working in a team could bring effective solutions. So I feel that instead of course like NIN100, this course should be taught included in the curriculum.*"
What kind of an effect did the learning have on your approach to solve problems? (0 being negative, 5 being no effect and 10 is positive)	8.56	A majority felt a positive effect on their approach to problems "*For an engineer, I believe it is very important to have a systematic thought process for coming up with ideas to solve problems and hence the need for this course.*"
What happened to the quality of solutions? (0 being they got worse, 5 is remained the same, 10 means got better)	8.56	A majority judged their quality of solutions for complex open ended problems to improve with this experience. The structure in the process reduced the noise of path finding with this time, eventually allowing them to focus their minds on the content, rather than the structure.

5 Discussion

Design thinking and creative problem solving are developed as independent from each other. However we think that a combination of both approaches would make the whole more than the sum of both. From a professional point of view, a typical Indian engineering student's profession is in one of the following: core sector, business administration, governmental administration, teaching and the recently evolving entrepreneurship. Each of these professional streams can be benefited by the abstract combination of design thinking and creative problem solving, which is to assimilate knowledge from multiple dimensions, work in teams and think from the perspective of the human on a complex open ended problem. This can be beneficial for Indian engineers as a tactical tool for the real life complexities they might face in their profession.

The vast spread of technical institutes in the country is a smart medium for the propagation and penetration of this mentality in the masses. The government has also realized this and is in the process of making a systematic plan for this intervention.

The study to understand the need and relevance of this way of intervening from the perspective of the most important stakeholder in this system, the students has resulted multiple positive directions for future development. The combination of design thinking and creative problem solving was felt relevant by a majority of the participants in the short duration of time they were introduced to it. However, for evaluating intervention, one needs a comparative study. The study, by and large is only an experimental one: there is no pre-test and post-test, and there is no control. This strikes as a limitation to the study, and hence, a follow-up study could be taken to create more concrete conclusion to the intervention. This can be in the form of a comparative analysis of two groups, one equipped with the understanding of design thinking and the other devoid.

To bring about such a course in just one institute can be a humungous task in itself. The primary roadblock is the access to well trained and capable faculties to facilitate such an education. Even if people from established design institutes commit themselves for some time for such an activity in engineering schools, the details of the exercises and the curriculum has to be very well structured such that the course is highly relevant for the students. Furthermore, to manage the design exercises for the quantity of students is another big hurdle for the intervention. In can be also argued that some streams need such an intervention more than others.

The marriage of design thinking and creative problem solving as complementary approaches has to be developed further to be more relevant for engineering education. The current level of adaptability was low and in the study, as it was observed that the participants had to make an effort to understand and build on the ideas of design thinking provided to them.

On a critical note, considering the top-down nature of Indian culture, the method of the study can be argued to be biased. However, given the time and situation, it was perceived to be the best way to intervene and evaluate their reactions.

Moreover, only student's responses are taken into consideration for this study. They are the most important, but one of many important stakeholders in the engineering education system of India. Also, design thinking and creative problem solving are few of the many ways to promote innovative thinking in engineers and spread awareness about design in a promising way. Surely, there is a need for further investigation for the near future in this context.

6 Conclusion

There is a dire need for an intervention at the foundational level of professional engineering education in India. Introducing design thinking creates a mindset which generates a perspective that focuses on the user. The creative problem solving process, with the main emphasis on the designer's thinking and acting can be a systematic approach for students to tackle complex open ended problems. The notion of design thinking introduces a philosophy which benefits the students by aiding them to think creatively and meaningfully already during their education but also carry this view into their future profession. This would also introduce a deeper, more meaningful notion of design in the minds of engineers.

Design thinking is a way to integrate creative, intuitive and analytical thinking. Information from multiple dimensions is assimilated to reach a holistic understanding and based on which a solution is created by a converging—diverging process. All of this is built on a user-centered perspective. Creative problem solving has well developed models for practical implementation of creative thinking in a systematic result oriented fashion.

A combination of these approaches was introduced to 30 students from the Indian Institute of Technology Delhi in a course for 10–15 h of engagement. The content was a combination of theoretical lectures, case discussions and practical workshops were students actively conducted a design process in teams, utilizing design thinking in the structured way of creative problem solving.

Engineering students perceive design thinking and creative problem solving to be relevant and beneficial for their education. There was a significant change perceived by the students in their approach to open ended problems from being haphazard and unstructured to being systematic and user centric. This structure was well appreciated by the students for the given problems at hand and they could imagine its utility in their educational courses, projects and later on in their professional career. Most students were in favor that it should be a compulsory course, but at the same time they questioned the value when the performance in this course is evaluated as grades.

Although the reported results are favorable, students are just one facet of the whole educational system. Further user and feasibility research is required to bridge the gap between the engineering and design education in the country for their mutual successful development.

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Appendix 1: Research Questionnaire

Part 1 (1 is bad, 5 or 10 is excellent)

For how many days did you manage to attend the course?

How would you rate the overall learning experience of the course?

1 2 3 4 5

With respect to your engineering studies, how relevant do you think is Design Thinking?

1 2 3 4 5 6 7 8 9 10

With respect to your engineering studies, how relevant is the creative problem solving process?

1 2 3 4 5 6 7 8 9 10

With respect to your engineering studies, how useful are the idea generation techniques?

1 2 3 4 5 6 7 8 9 10

What kind of an effect did the learning have on your approach to solve problems?

1 2 3 4 5 6 7 8 9 10

Part 2

Comparing to the last day's experience to the first. (1 is bad, 10 is excellent)

What happened to the quantity of ideas?

1 2 3 4 5 6 7 8 9 10

What happened to the quality of solutions?

1 2 3 4 5 6 7 8 9 10

How about the process? What effect did it had on the final outcomes?

1 2 3 4 5 6 7 8 9 10

How was the experience of working in a team?

1 2 3 4 5 6 7 8 9 10

Part 3

Do you think that 'design thinking for undergraduate engineers' should be a semester course (like an elective) for all students?

Y/N

Why do you think so?

Any suggestions for improvements?

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Design Considerations for Personalized Learning

Vimal Anand

Abstract With the education changing at a rapid speed in the coming years. A large population is moving towards digitized learning. In order to have quality education, more learning methods need to be incorporated in the learning process which suits the learning styles of an individual. This may enable a large mass to have an immersive learning and retain the essence of learning that can be incorporated in their everyday life. Manifesting the learning styles of a person and providing methods for improvement is a necessary need in the web based learning of education. With the main focus on teenagers who find themselves confused with decision making and their learning ways, as it does not match with the current process of teaching. Quality learning tools for teaching are necessary to promote personalized and self-directed learning. A blend of Interaction and instructional design can be used as tool to facilitate personalized learning and help explore styles suitable for a learner. And also with the information overloading, a holistic approach towards learning improves decision making of students studying.

Keywords Self-directed · Learning · Instructional design · Personalized

1 Introduction

> "Winners don't do different things, they do things differently"
>
> —Anonyms

Certainly the quotation states that learning is personalized and a required necessity to perform better by changing its way of thinking and doing. The study focuses on the learning methods adopted by individuals with a keen insights of the

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process thinking and developing a methodology for learners. With the increasing in digitized education and easy access to information, e-learning is an immerging market among learners. But the learning platforms are not completely suited with the needs of the learner. As well as techniques to learn the way there personality suits is ignored and needs to identify with the changing needs of a user and focus on enhancing the metacognitive learning of the learner with an adaptive environment provided. It is necessary to encourage and support these efforts at every level—classroom, school and curriculum. By empowering, we mean practices that foster choice and voice, that free the learner from only one way of knowing, that create an emotionally-safe culture, that support meaning-making, that allow learners to feel successful and bring a high level of engagement through the learning process.

1.1 Focus of Work

The models of learning styles can be categorized into different approaches to learning. According to a model by McCarthy (2010), there exist four approaches to learning: personality, information processing, social interaction and instructional preferences [1]. Work focuses on the outcome of the student with evaluative feedback necessary for the learner. It highlights the main problem concern with the learner's motivation to perform better and providing necessary tools to perform their task effectively. On choosing to learn a task, a learner is already equipped with certain skills and tools to acquire the knowledge of learning topic. Certainly they are different skills set and tools required to perform different learning outcomes. As well as different topics require different skills and tools to give a useful learning outcome for the learner. The skills, tools and material available with many options to get a learning outcome but with many options comes confusion to the user as due to information overloading and unable to choose the right learning path for a desired outcome.

2 Literature Review

2.1 Learning

"Learning as a social activity, as an engine of creativity and innovation, and productivity in society, is going to be exploding in the foreseeable future. And it is also going to present many, many possible alternatives for leadership and for development of new and powerful modes of learning" By Prof Richard Elmora [2].

2.2 Self-directed Learning

Knowles (1975) described Self-Directed Learning (SDL) broadly as "a process in which individuals take the initiative, with or without the help of other, to diagnose their learning needs, formulate learning goals, identify resources for learning, select and implement learning strategies, and evaluate learning outcomes" [3].

Tan et al. (2011) describe the processes of SDL based on a series of requisites or qualities:

(a) Ownership of learning
(b) Self-management and self-monitoring
(c) Extension of own learning.

Self-directed learning is approach through which students may diagnose their learning needs to formulate their learning goals and implement their own learning strategies. The learning outcomes from the student can be evaluated and can analyze user needs such as [1]:

- Responsibility to perform better and take decisions associated with the learning endeavors.
- Student may view its strength and weakness to some degree to the learning situation.
- Performance in learning environments.
- Comparative transfer of knowledge to other learning environments.
- View learning as an outcome to diagnose various areas of needed learning.

2.3 Research Question

The focus of the problem was to touch learning methods and techniques which students use during their studies and how they can manifest their strengths and weakness to harness an improved learning outcome. As discussed earlier, the learning process which defines the user learning by using certain skill sets and tools to give the required learning result which the learner needs. A right approach for individual learner is needed to personalized learning and self-directed approach.

Certainly in Indian context personalized education has lot of challenges, which Indian curriculum fail to provide to the students. With teacher student ratio not in good numbers has further enhanced the problem. Thus a constant pace of a strict schedule of curriculum in schools, which says one size fit to all has been the key problem area, which needs to be focused. A large syllabus which is not student centered is also a major problem for students.

This further lead to intensive case studies on open online courses done which aim to provide personalized learning environment. Finding the key problem which field research focused to provide a better iterative design for online learning.

With that, a questionnaire was designed to find some user insights and that may help to enhance personalized learning experience. The questionnaire aimed at collecting data from three point views of the user. Firstly, with the students thoughts of his current school learning relating to his teachers and studying environment. Secondly, on the how students connect their learning with their home environment and content provided to them to study. And thirdly, some insights on their learning approach to be a successful learner with the present constraints to them. The problem is more severe one at the school level, where a lot of talented students interested in different fields are getting into streams not of their interest.

3 Quantitative Field Research

The problem finding of the project started with finding learning gaps within students studying the present educational curriculum particularly teenagers. A primary data collection of 45 students was collected via a questionnaire which indicated few insights after the analysis of the survey (Figs. 1, 2, 3, 4, 5, 6, 7 and 8).

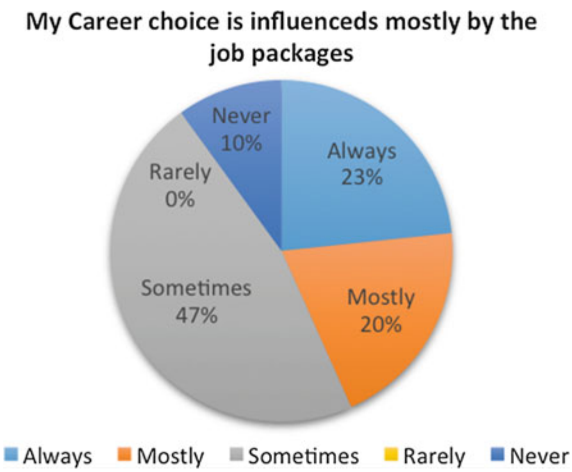

Fig. 1 Sample result of Question—How Career choices are influenced by job packages?

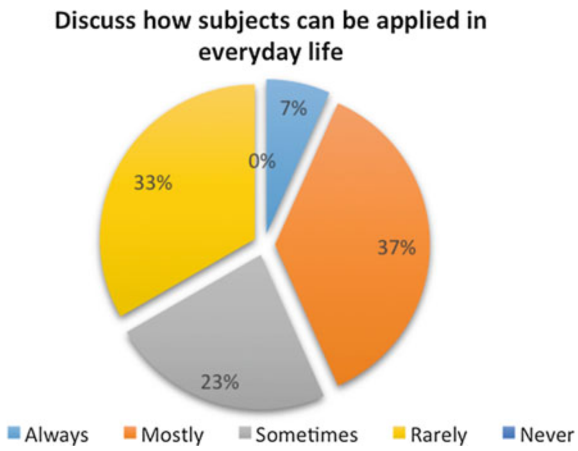

Fig. 2 Sample result of Question—How subjects are applied in everyday life?

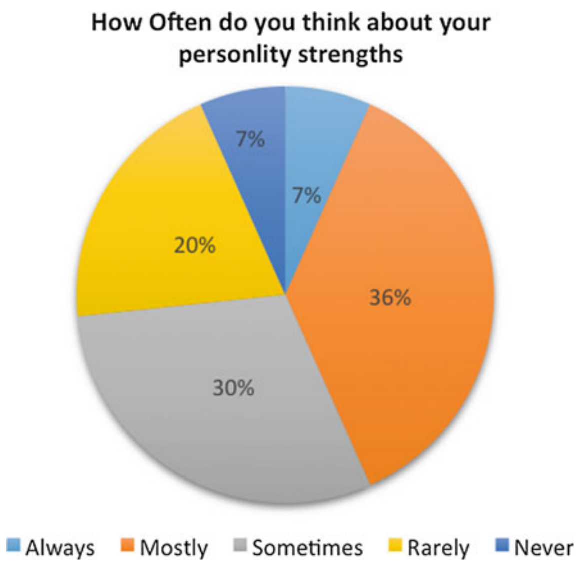

Fig. 3 Sample result of Question—How often personal strengths are considered important?

Fig. 4 Sample result of Question—How important are personality test considered important?

Fig. 5 Sample result of Question—How frequently questions are asked during studying?

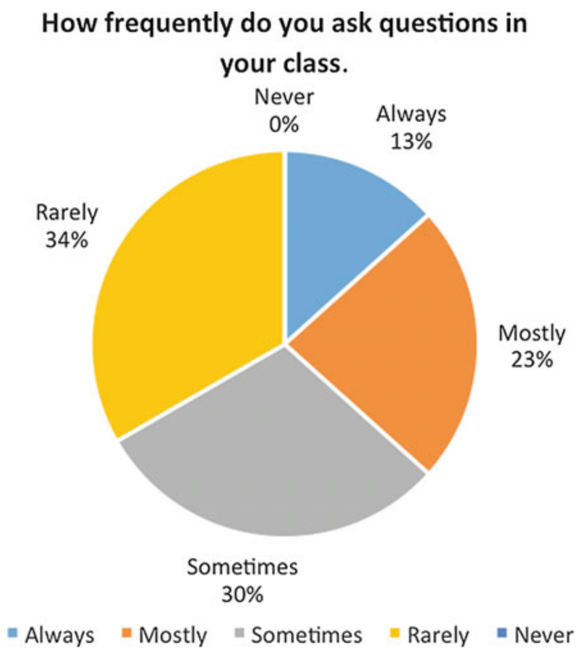

Fig. 6 Sample result of Question—How much effort is tried on improving studying habits?

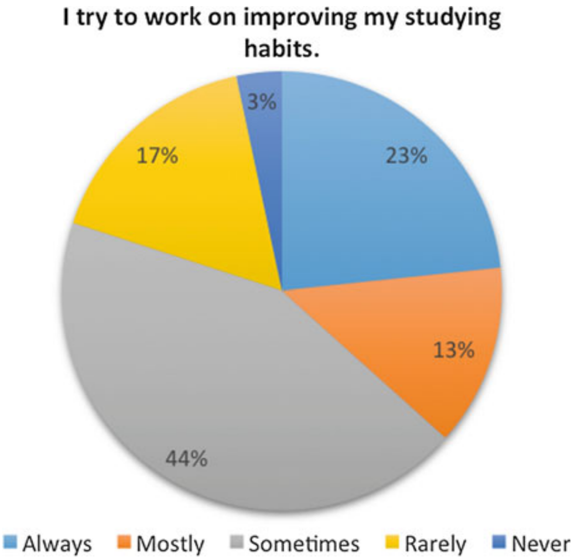

Fig. 7 Sample result of Question—How much consultation is done with parents?

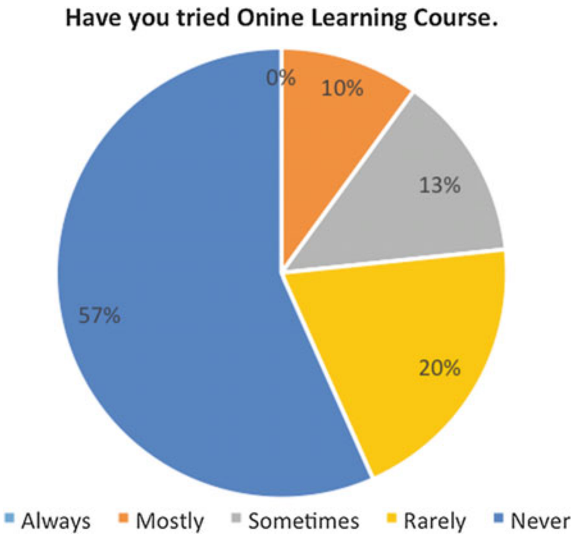

Fig. 8 Sample result of Question—How much Online learning takes place?

3.1 *Insights from the Data*

1. Improvising the Study habits are ignored by most of the students.
2. Very few number of students can relate their course work with the everyday life of working.
3. Students consider personality strengths to be useful for their studies but do not know how to improve.
4. Majority of the students do not ask questions or avoid asking questions to the teacher.
5. Very few students do online learning courses but large number of students have at least tried online courses.
6. Mostly students take consultation advice from their parents but not their complete priority.
7. Pay packages influence most of the students in the choice their career than their own personal strength.

3.2 *Persona*

On the contextual inquiry and interviews, personas are build which depicts the target group and divides on parameters of learning goals, methods, problems and resources.

Persona#1

Personal information	• Name: Ravi, Male • Studies in 8th grade • Scores around 60%
Interest areas	• Works hard in all subjects but performs well in few subjects • He dislikes certain subjects and completely ignores them
Learning goals	• Aims to secure high marks • Adapt to all subjects but knows his interests • More Job oriented • Wants to work on his strengths
Learning methods	• Repetitive memorizing • Visualization and imagination • Enquiry and exploration methods
Learning problems	• Does not revise often or back trace his work • Poor planning for his study habits • Wants better study material for his weak subjects
Learning resources	• Does not frequently study course text • Internet as a resource for his subjects of interests • Online Social Networking

Persona#2

Personal information	• Name: Sheela, Female • Studies in 10th grade • Scores greater than 95%
Interest areas	• Performs diligently in all subjects but has interests in language and arts • She dislikes certain subjects but still excels in them
Learning goals	• Her learning goal is to perform well irrespective of her interests • Her motivation is job oriented
Learning methods	• Repetitive revision techniques • Writing and memorizing/summarization • Often reading books and revision • Plans her schedule
Learning problems	• She quits a math problem very easily if she not able to solve it • Often take help from teachers before attempting some tough problems herself
Learning resources	• Prefers to study course text • Takes some additional help from internet resource

3.3 Benchmarking of Current Digital Products

By doing the benchmarking, certain points are gathered as below.

3.3.1 Case Study #1 (EDX.org)

- Providing career related options for the learner can be a motivation to continue studying the course. Digital tools are providing awards which helps the user enhance its career skills and also showcase on social media. Also as shown in Fig. 9.
- Auditory and visual pace access to the user for easy understanding as per its own pace. As well as providing a holistic view for a better understanding. As also depicted in Fig. 10.

Fig. 9 Benchmarking-Edx.org profile dashboard displays learning connection to your career profiles on Linkedin, as well as provides certification

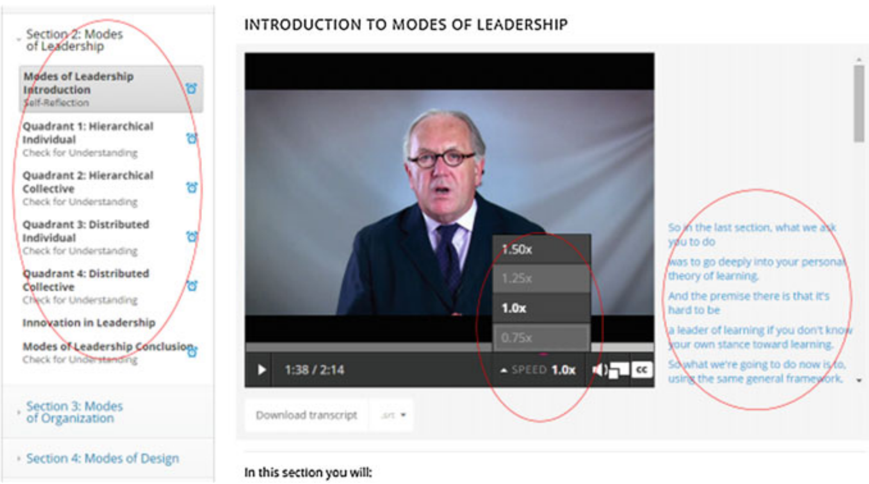

Fig. 10 Benchmarking-Dashboard provides holistic view of learning with personalised visual and auditory pace to the user

3.3.2 Case Study #2 (KhanAcademy.org)

- A road map ready for the user to see its progress and also parents can connect and give feedbacks in the course of the child.
- Award points provided for the students on completion of the course and the success rating in progress.

4 Design Framework

With data insights and user research, a structure of design development was needed to be defined with further analysis of current working products. This section will discuss the ecosystem of the learning environment, which is been focused in the project. And taking benchmarking of current products in the market which aims to provide personalized learning to users.

The main focus of analysis is to improve personalized learning more on online learning courses and observing their good practices. There are certainly gaps of improvement for personalized learning on the courses. The insights from the research phase serves as a better understanding of the current ecosystem and products in market.

- Defining various components of personalized learning.
- Capturing the learning experience to aid with the concepts of learning tool.
- Feedback loops beneficial to users for learning.
- The workflow and navigation of the learning skills.

The end goal of this stage is to end up with solid design concepts which can be detailed and refined for development and implantation. Some of the factors contributing to the student learning can largely be categorized in:

- **Competition**: Students learning are deeply affecting by the competition around the student which are influenced by parents. As well as a constant pace of the courses and strict learning schedule to compete with the learning environment around the student.
- **Resources**: The quality of the resource provided to the student with books, teachers, school infrastructure and additional help can play an important role in influencing its motivation to learn in its environment.
- **Skill Learning**: Basic skill sets for learning are a basic need of an individual to perform certain task and improve its learning. It includes the three R's which are reading, writing and arithmetic. But the skill set required to learn is hindered by the personal development needed and their learning styles.
- **Opportunities Provided**: The opportunities to the student and the learning it is provided can blend to be a major role in the decision making of the student for its future. The opportunities include current jobs, skill training and learning techniques provided and learned by them.

- **Feedback**: A very important component of the ecosystem which can improve on a student performance with corrective feedbacks. With the current scenarios report cards and assessments play a major part in evaluating and providing feedback to the students.

4.1 Considerations Gathered for Learning on a Platform

- **Top-down Approach**: A top down approach to learn a context is important, as holistic learning helps a user define its learning path and build a better view of the subject. It gives an approach to plan learning and schedule according its style. Down-top approach leads to weak base and forces the learner to memorize in forms of chunks [4].
- **Building Connections**: Connecting learning with everyday things and making learning a routine with connections around can help a learner retain in its memory. This may be linked their interest areas or the motivation which they intent to learn a topic. They can be instigated to learn with their own ideas and connect with people around for guidance and common interests. Opportunities can be given to a learner which can be a related to its current working area to enhance its learning experience [4].
- **Personalized Set Up**: A personal setup of learning can fasten the process of learning which can be defined by the learning styles and personality of an individual to learn. As well as the pre-experience and knowledge it has acquired before the task is assigned to the learner to learn. Personalized learning certainly gives rise to questions of their learning choice and the learner needs. The learner can be guided by pursuing with a routine of work and providing the changes it require in its skills of learning. A learner choice and its need should be a blended part of its raw skills and the routine work it performs.
- **Feedback**: A comparative feedback for a learner after having a outcome can help a learner visualize its mistakes and improve on it. Learning Strategy provided which can be improved, by the learner actions of adopting it. With the feedback to the user to check changes can help it to improve on by modifying its actions.
- **Self-Paced Learning**: A strict scheduled learning often leads to improper concept building, as every individual has its own pace and prior experiences which enables it to learn certain concepts. A self-paced learning has many advantages to learn better, such as:

    1. **Exploring**—certain concepts related to the subject helps the learner identify its personality traits and use its strength and weakness according to the tasks available for the course. This may also lead to tracing back which links many other ideas to the new learning to understand the concept better.
    2. **Self-Directed Learning**—indicates choices of strategic learning which can promote self-explanatory habits in the learner. And motivating learner to visualize and create metaphors for its learning. A story board approach can also help a learner summarize the learning outcome. As well as grouping information with personalized categorization.

4.2 Designing Learning Tool

The skills a learner demands and the skill provided by the learning instructions should be in balance. Learner is provided with techniques to have the correct blend of the skills acquired by it. The motivation for the skills to perform is an important factor to be considered in the skill sets. Hence with a relevant data feedback to the learner can help understand the correct personal skill to be required by it.

With the motivation to perform may lead to exploration and some result outcomes. The results coming and the results expected needs to be in balance with the learner needs. As exploring may lead to lots of different outcomes, giving many results to confuse the learner. A feedback can be applied with better pattern recognition on the approach taken and options chosen to proceed in learning. A task outcomes and methods can be recorded and provide a feedback to the task given earlier. This may help to modify and recommend personalized tasks for the learner. This may help the learner to adapt to the learning environment with personalized setup (Fig. 11).

The choices made are observed on the priorities of the learner. And with priorities required for the action plan and action taken can yield certain results which may or not match with the learner expectations. Priorities defined with the required action plan can give help in performing the right action to give the desired result expected from the learner. This may also predict the best suitable learning path for a learner. It can be compared with the previous results of the combination in priorities taken and actions performed. This may leads to explore self-directed action monitoring learning ways, as well as experimental ways of learning. Action monitoring may further lead to analysis of strengths and weaknesses of a learner which can be filtered. The combine percentage needed for the learner growths can be provided to tasks given. This will provide the user the feedback of advantage and disadvantage over characteristics and an overview of having control over its learning. The tasks can continued to be recommendated matching with the traits of an individuals learning styles. And the percentage filteration of strength and weakness can be modified and monitored to give a balance growth required according to the needs (Fig. 12).

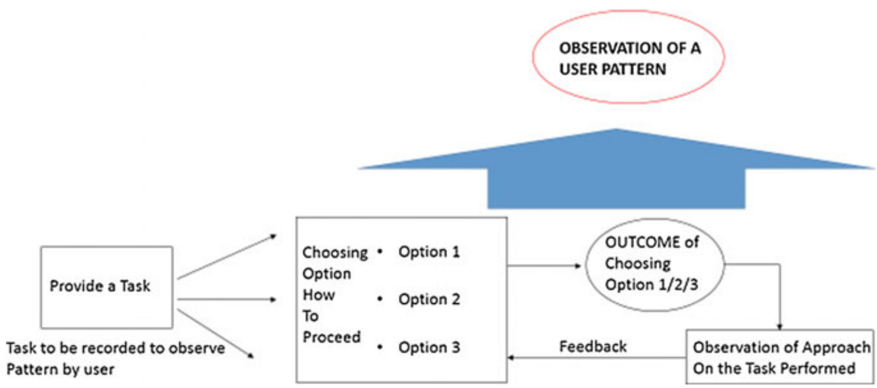

Fig. 11 Feedback of learning recommendations in the learning tool

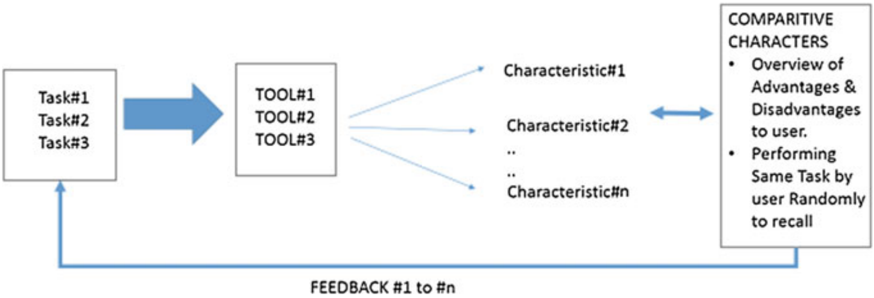

Fig. 12 Comparative characteristic study in the learning tool for its personal strength and weakness

4.3 *Interface Concepts*

The learning tools can be effectively used on the interface by the learners. The following widget designs are the recommendations that can be used to enhance personalized learning.

- **Concept 1**

The components of learning should be easily available to learner which can be modified with learning experience of constant feedbacks given to learner. This may enhance certain strengths of learning which is required by its work. As well try to improve on its weakness and placing components with recommended feedbacks to the learner. In Fig. 13 shows different components of learning placed accordance to learner needs. Tools such as note keeping and highlights of the learned concepts earlier with its personal touch of widgets can help the user for an immersive learning. Even audio and video session to be controlled by users for a better visualization and personal connectivity to learn.

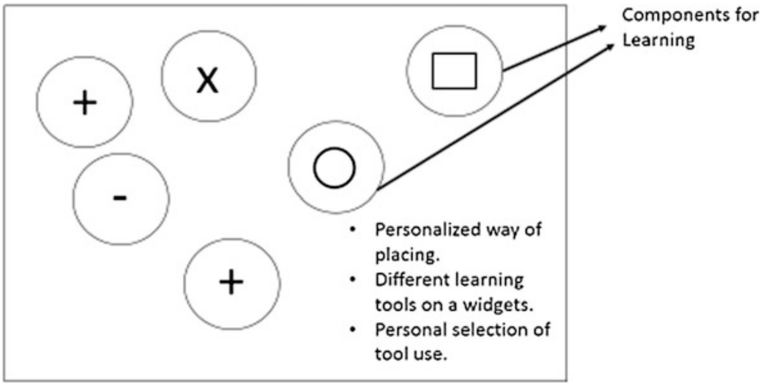

Fig. 13 Personalized widgets

- **Concept 2**

The mode of communication been used for learning such as video watching or text running. During the course running, their small concepts which are ignored in making understand a big concept. Certainly a step by step learning and breaking it into smaller concepts may give better in applications. The concepts can be highlighted for user preference to refer back and create better connections with the new learning.

Example a physics concept is built of many small concepts to form a bigger concept. Explaining many small ideas are also important for a better and detailed understanding of a concept. This may help to improve the application and ease of studying (Fig. 14).

- **Concept 3**

The video in display for learning or the text has certain key words which may help in building metaphoric connections and help to remember and analyze later to improve on its learning more effectively. Learner may create its story board for better revision and summarization on its return back to the widget. Certain Key words and saying are skipped during a course study, rather there should a bank of words explained and providing techniques such as story boarding and metaphor reference for easy building of connections of what the user wants to learn. A well as providing feedbacks of what the user is missing in its learning shall be good insight of the learner and may work as self-reflection for it (Fig. 15).

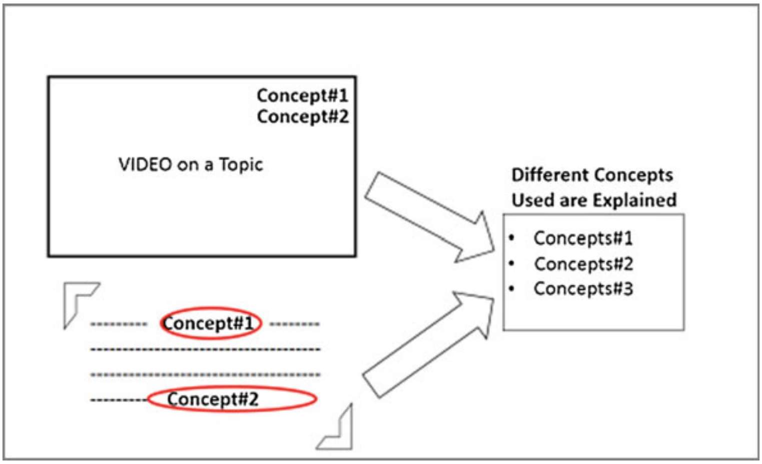

Fig. 14 Personalized smaller breaking concepts

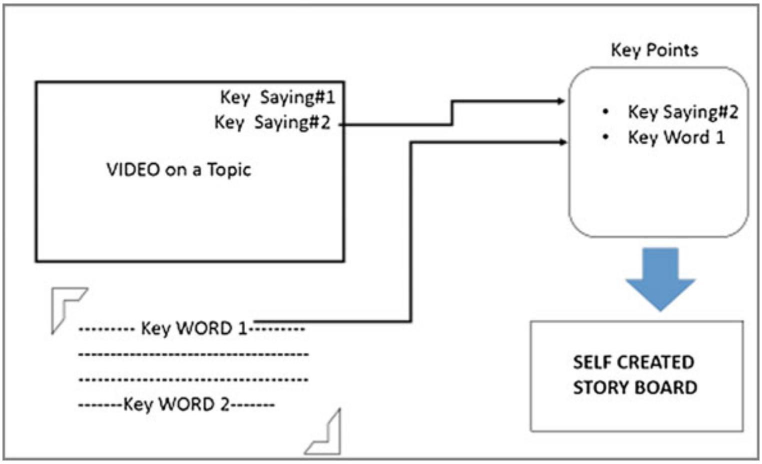

Fig. 15 Personalized note making and story building

5 Conclusion

With the advancement in the digitized world of education, with more and more online courses available in, by world renounced universities. Information is at our figure tips but a necessity of channelizing the information according to user has to be provided for a better improved learning environment with effective learning takes place. In conclusion, it is necessary to reiterate that the focus of this process is on the study of personalized learning theories and models, meant to design and recommend the needed interaction and instructions for a learner. The concepts mentioned exemplify those principles and guidelines. The project attempts to provide personalized components suitable for the learning style of a learner. The components of personalized learning can be categorized into:

- Learning Strategies to find a corrective approach to solve a problem.
- Feedbacks on its learning outcome to improve learning iterations.
- Learning Characteristic with a comparative approach to improve learning.
- Personal Goal and task oriented learning.
- Tracing the Learning Path for better feedback connections.
- Iterative development of the design by the learner.

These points are considered during the thesis project for the designing the learning tools and concepts, however the implantation will require deeper and belter defined inroads.

6 Future Scope

With a rapid advancement in technology in the past decade has led to more personal space for an individual, in which education is moving towards a big change in personalized learning. The advancement in analytics techniques has given birth to new fields like learning analytics and data mining in education. The future lies in enhance high-level thinking and learning across disciplines in a range of contexts, including schools, businesses, museums, and digital environments.

Analytics in learning is also perceived as a reliable tool for decision making as well as for achieving greater levels of adaption to improve personalization that are evidence based to the learner. Analytics in education borrow techniques from different fields, such as Educational Data Mining (EDM), Social Network Analysis, web analytics and Information Visualization in order to come up with tools and methods that facilitate the exploration of data coming from educational contexts.

The learning tools can be applied to learning analytics and instructional design concepts to improve the current learning state to a higher level of thinking for self-directed and personal space of learning.

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A Conceptual Model for Introducing Design Thinking in Management Schools

Cedric Serpes and Gayatri Menon

Abstract The paper investigates the need for introducing design thinking in business schools and proposes a conceptual model for the same based on community design intervention. Innovation is increasingly being seen as a core competence requirement for industries. Innovation requires a synergistic confluence of design, technology and management. Business management students need to be equipped with design thinking in order to creatively manage and lead innovation in organizations. How can design thinking be introduced in business schools? What are the methods which could enable business students to arrive at user-centered, creative ideas and opportunities? What could be the mode for internalizing these learnings? These were some of the aspects considered in order to prepare a framework for the case study. It was decided to introduce business management students to opportunity identifications as well as creative design thinking through a community based intervention approach. Case study analysis was used to analyze the major problems faced by the students throughout the project as well as the key learning of the students during the project. Some of the major problems faced by the B-school students during the project were in terms of their overall approach to the project. The analysis further resulted in a conceptual model which proposes the following key learning: (1) Meaning and value (2) Concerns (3) Empathetic understanding of stakeholders (4) Creative thinking (5) Opportunity identification and extension. The proposed conceptual model is expected to help business schools introduce design thinking to students through collaborative community based projects.

Keywords Design thinking · Collaborative projects · B-school · Pedagogy

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1 Introduction

Today's marketplace is increasingly dynamic and given the changing demands of people and business, it is becoming important to think innovatively rather than merely implement random ideas. "Innovate or Die" is the new mantra and the reality of successful business strategies. Business schools, however, largely ignore the nature of innovation, which includes converting a problem into sustainable opportunities for commercialization or community development. To achieve sustainable innovation in business, whether for commercial reasons or community development, there has to be a synergy between design, technology and management. Without new ideas or new approaches to old and entrenched concepts, businesses will stagnate.

The need of the hour is to introduce fresh ways of thinking and problem-solving to management students, largely comprising of high-ranking mechanical and computer engineers and successful students with similar backgrounds. Business schools teach and reward scientific decision-making, rather than designing new solutions. Traditionally, B-school education has been myopic in including only case study analysis and theoretical concepts as the main pedagogical approach. Typically, market visits and industry internships are as far as they go to introducing students to a practical approach to business management. Innovation, if included in the curriculum at all, has been restricted to innovation management and implementation, rather than new idea generation and opportunity identification.

This paper examines the experiment in design thinking for a group of B-school students to develop sustainable solutions to a waste management problem through community based projects. A Community Social Responsibility, CSR project provides a great opportunity to introduce and implement a design thinking framework to teach students to explore multiple solutions and identify opportunities relevant to the community which could benefit from the solutions.

2 Need for Introducing Management Students to Design Thinking

Making decisions through precedents may have worked in a stable and unchanging environment, where firmly entrenched formulas of business or management or problem-solving worked because of the limited possibilities and needs. In today's world, however, where people, things, demands and needs change dynamically, set formulas for problem-solving restrict growth. Whether it is marketing, organizational behavior, finance or IT, any business that is not nimble and innovative will stagnate. It is imperative then that we give the practice of innovation an organized methodology, a broad framework of rules within which creativity can flourish exponentially.

Understanding the techniques of brainstorming and critical and creative thinking and analysis does not necessarily make B-school students innovation-ready. Idea generation and "doing" innovation needs to be inculcated through involvement in the innovation processes in school itself—students needs hands-on experience in understanding the processes involved in teasing consumer insights, crafting solutions that are relevant to the stakeholders involved and testing and prototyping appropriately [1]. Design thinking, rooted in people-centric solutions, provides just the right framework within which one can have a multifaceted, rich tapestry of solutions.

The digital revolution has changed the business scenario as much as the industrial revolution did in the late 18th and early 19th century. Today, technology is available to us much more freely than ever before. The internet and mobile phones have changed the way business is done. New businesses have been spawned and new ways of doing old businesses have emerged. These are the principles on which design thinking also work. If managers were to use existing and expanding new technologies, apply the principles of design thinking to develop products and services, they can achieve life-changing results for the stakeholders of their industry.

3 Key Aspects to Design Thinking

There seems to be a natural evolution from design doing to design thinking, the principles of which are applicable to a wide range of organizations through not only products but also processes, services, interactions, systems etc. [2]. Due to the increasing recognition of design thinking as a key factor for innovation in many organizations, it is increasingly being used not just by designers but also by other professionals. In fact, it is being suggested that business people not only need to understand designers better, but in fact, they need to be designers [3].

Design Thinking is essentially human-centric designing. In fact, innovation driven by design thinking are initiated by empathetic understanding of people and developing concepts around them before conceiving business around such concepts [4]. Design Thinking begins with empathy, the intrinsic and insightful understanding of the people for whom the solution is sought. Putting oneself in others shoes takes on a deeper meaning in design thinking. Identifying and observing the stakeholders as they experience their "pain" is a critical aspect of the journey in developing empathy.

Empathy and observation is what leads to finding, framing and reframing a problem -that is at the heart of design thinking philosophy. And the two key aspects are people and problems. Arriving at solutions through design thinking also takes a multifaceted, collaborative approach. It is generally found that the more varied and diverse the collaboration, the richer the solutions. The tools of design thinking include visualization, problem-definition, collaboration, prototyping, iterative ideation, testing and implementation.

Design thinking involves not only analytical, synthetic and creative thinking but also intentional thinking involving meanings and values as well as explorative and reflective thinking [5]. Thus experiencing the process of design helps in understanding this wide range of thinking patterns.

4 Pedagogical Approaches to Integrate Design Thinking in Management Schools

Current models of pedagogy in business schools are quite out of context, especially in the Indian scenario. Moreover, given the dynamic nature of the marketplace today, teaching merely based on past experience is not productive.

Real world challenges are complex and dynamic. B-school students need to be introduced to real world challenges so that they develop experience in handling complex situations. Instruction that uses design thinking methods can teach students meaning and value without arming them with a prescribed set of theories and options [6].

4.1 Existing Pedagogical Approaches

Teaching potential managers to apply the mindset and methodology that designers traditionally use to develop innovative products and services is still very nascent. Programs like the boot camp at d-school, the Institute of design at Stanford, provide a live project approach to teach students design thinking.

(a) Lecture/Knowledge based

Lecture-based study does not offer a point of differentiation between potential managers from different management schools. Moreover, in a fast-changing marketplace, having a set of tried and tested theories and rules does not help. The world has become too complex and there are myriad solutions to problems. Knowledge, purely based on formulas and principles that worked in the past, is not sufficient to navigate the current landscape.

(b) Case study/Internships

Most business schools rely on case study methods and industry internships to impart real life exposure. However case studies end up giving a historical perspective rather than an experiential learning experience to students. At most, industry internships are the only exposure students have to the real world, but even here there is no attempt to understand the stakeholders involved.

4.2 Proposed Pedagogical Approaches

(a) Project based

Design thinking methods can be taught in business schools, through live projects. Creativity, Innovation and Design Thinking as a consolidated course can begin with teaching students practices of creative thinking. Some of the aspects of creative thinking include imagination, visualization and uniqueness. Students are taught to be imaginative, through various exercises. Going a step further from imagination, students can be taught to apply the principles designers use—analyse, synthesise and evaluate in a more rapid cycle, almost simultaneously [7]. The students would adopt projects that would allow them to apply the principles they learn in the classroom.

(b) Real life context

Finding solutions in a real-life context would give students immersive, experiential learning. Exposure to real situations and real problems prepares them to understand the complexities of people, their needs, relationships and the societies they live in. Real life contexts work like simulations for future navigation and enable students to develop design thinking abilities for their professional future.

5 Case Study

It was decided to introduce management students to opportunity identifications as well as creative design thinking through a community based intervention approach.

The project: Shanta Durga temple generates almost 900 kg of Marigold flowers per month. These flowers are offered to the deity and then left on the premises, piling up. These flowers could not be trashed as they had perceived religious significance. As a CSR project, this was a small group where a teaching framework could be experimented and scaled to the classroom. The project involved a total of seven students. They were holy offerings, so they could not be thrown out as garbage. Being wet, they could not be burnt without causing environmental distress. The temple authorities with the help of a biologist had attempted to convert this waste into vermicompost. This could not be sustained as the procedure required skill that could not be transferred easily.

It was expected that this community based intervention approach would help in bringing rich real life experience into classroom education thus helping students to internalize the learning pertaining to design thinking in an experiential manner. The approach would also enable students to be self motivated and look for opportunities around them rather than be client driven in looking for opportunities. The local communities would benefit directly through the business opportunities generated and indirectly through learning approaches to solving problems by working together in a collaborative manner on the project.

Field study and creativity sessions: Empathy was arrived at through a series of visits to the temple and the villages around the temple. Students watched and recorded the activities around the location. They were instructed to perceive the location from a bird's eye view point and think of possible solutions through collaboration within a 1 km radius around the temple.
Students asked a series of questions using visualization and creative techniques.
Example:

1. What do you do with dead flowers?
2. Can we sell them?
3. Can we dismantle them?
4. Can they be drunk?
5. Can they be eaten?
6. Can we bury them?
7. Can we dissolve them?
8. Can we cook them?
9. Can we recombine them?
10. Can we convert them?
11. Is there a solution we can see if we were crows on the temple roof?
12. What do the flowers look like to a dog?
13. What do flowers look like to a worm; to the soil; to the rain;

The solutions:

1. Vermicomposting—for selling to farmers and vegetable garden owners
2. Manufacturing Incense sticks—branded for sake at the temple store
3. Incinerate the flowers—holy ash for sale
4. Prepare a Pot-pourri—to be sold for domestic use
5. Organic colour—despatch to nearby factory for colour extraction
6. Healing oil/Packaged Floral Blessings—for temple sale
7. Recycled paper from flowers—boutique sale
8. Cattle feed to be consumed by second day after offering.

Prototyping: Owing to time constraints, students tested the first three ideas, drawing a systems map, identifying costs and stakeholders who would benefit from each idea. They visited factories that were engaged in similar businesses—an incense stick manufacturer, a local farmer who undertook vermicomposting and an expert in solid waste management solutions. The students also roped in local MLAs and panchayats to discuss issues and concerns of the villagers, in a bid to identify opportunities, as well as deploy solutions. Eventually through elimination, they arrived at the best possible solution for the temple authorities and the farmers benefitting from the organic compost.

Thus B-school students under faculty guidance explored diverse ways to solve a single problem. In the process they went beyond solution and discovered sustainable business ideas that converted the solution into multiple business opportunities

Fig. 1 Design prototyping and testing

for the stakeholder. The response also delivered solutions that could be extended and replicated enabling opportunity extension (Fig. 1).

6 Challenges and Key Learnings

The biggest challenge faced was the time constraint. Students met with the stakeholders once a week. Other problems were typical B-school indoctrination issues, which included arriving at quick solutions rather than understanding various dimensions of the problem; logic driven solutions rather than creative, unique solutions and inability to come up with a range of diverse solutions. Students tended to give up easily. They were also less inclined to experiment.

Analysis of the process helped identify creative methods and design approaches which enabled the students to break away from the set pattern of thinking. The analysis further resulted in a conceptual model which proposes the following key learning.

6.1 Meaning and Value

Students need to understand the concept of Meaning and Value and the correlation between the two. Meaning is a contextual issue. It changes according to people and contexts. Changing the value of something will result in an altered meaning. Meaning is what drives people. To understand and empathize with people, we need to understand how they see things, and how they assign meaning to them. When we understand the meaning, we can manipulate it by changing the value.

The key learning here was the understanding of the meaning the flowers held for the temple authorities and the devotees. Nirmalya, or offerings made to the Gods, could not be disposed in a "callous" fashion. It was a sacred waste that needed to be disposed, but treated with respect.

The students understood the need to change the "waste" into "resource", changing its meaning and therefore its value. The first option they came up with was converting the flowers to agarbattis, as it was in the same genre of sacredness. Holy ash for sale and dried flowers as temple blessings were also logical and meaningful options. The value of the waste would have increased exponentially.

Organic wire mesh composting was the final option chosen as it worked both for the temple authorities as well as was meaningful to the farmers who accepted it. The prospect of receiving large quantities of organic compost at no cost appealed to the economically backward farming community and was a mutually beneficial and sustainable idea.

The major learning here was how meaning changes depending on the stakeholder. The same situation and solution is valued differently by different people. What the temple authorities perceived as waste could be a valuable resource for another stakeholder. Thus the meaning and value with respect to temple waste varied amongst the stakeholders. Understanding of meaning and value was critical for the students to later come up with solutions which are feasible and culturally appropriate.

6.2 Empathetic Understanding of Stakeholders and Concerns

In this study, there were many levels of stakeholders. The first task is to teach students how to identify the stakeholders. A lot of people who were currently not part of the pattern, could become part of the solution. So empathy has to go beyond understanding the people with the problem. The solution could lie in empathizing with the situation as well. Once the new stakeholders have been identified, understanding their background, issues, meaning and values could provide deeper insights and diverse solutions to the problem.

The students started with understanding the temple authorities and the location and identified the villagers as the new stakeholders. They further understood their concerns and needs and tried to get them resources for sustainable employment, while solving a problem elsewhere.

6.3 Creative Thinking

For the students, one of the major challenges was that they did not believe they could come up with creative solutions. They were comfortable picking the first solution that occurred to them. Business school students believe in a lot of fallacies: firstly, that they are not creative and are not capable of lateral, out-of-the-box solutions. They also believe that it is not their "job" to come up with ideas—they only have to manage existing portfolios of their company. They believe that creativity is the domain of start-ups. None of these fallacies are valid. Questioning techniques used in design thinking can throw up solutions which are simple, but logical. The creativity lies in forging new solutions, simply by seeing things differently.

To get a breakthrough, students were exposed to various visualization techniques—become a crow and get a bird's eye view, look at the problem through a cow's eyes, look at the situation through a devotee's eyes. Next, look at the flowers, observe them carefully, note the details, write down words that described the flowers. Students came up with things like colour, fragrance, organic, holy, sacred, etc. These words threw up solutions such as colour extraction and dyeing, pot pourri, agarbattis, and composting. The time constraint allowed them to prototype some of the ideas and test them against various parameters such as financial feasibility, physical constraints, etc.

The ability to be creative can be taught through various techniques in the classroom. This would enable students to gain self-confidence in their ability to think creatively.

6.4 Opportunity Identification and Extension

The waste management solution proposed for the temple threw up a slew of opportunities for the neighbouring villages. Agarbatti manufacturing could have provided a good business opportunity for the villagers. It was sustainable, but not feasible in this case. The vermicomposting provided a resource to farmers who could now use organic fertilizer, rather than chemical fertilizers. Their produce could now be sold under an organic banner and would fetch a better price.

The opportunity was identified and was later on sought to be extended in order to increase the impact. This model could work for any temple waste anywhere in the country. Temples are typically situated in villages such as the one in this study. The needs of the villagers who form the lattice around temple complexes such as this, are quite similar. Not only is it a feasible way to dispose waste but can also generate opportunities for employment and business generated through temple waste management in other parts of India where this problem exists.

7 Conceptual Model

The intention of this study was to develop a conceptual model for introducing design thinking to B-school students, in order to arm them with relevant skills to deal with an unstructured and rapidly changing marketplace. The essence of design thinking is collaboration. It is important and imperative that business schools collaborate with organisations to provide students live problems as projects on which they can learn experientially. Collaborating with social organizations from their immediate environment has the added advantage of the enabling the students to realize that design thinking can help them to make a critical creative difference and bring about a positive change in their environment (Fig. 2).

The conceptual model proposes a method through which design thinking could be incorporated in B-schools. It is proposed that the B-school can collaborate with an organization to work out a collaborative CSR project. The CSR project will provide real life experience on incorporating design thinking to arrive at business opportunities. The students under the guidance of faculty will understand key stakeholders and use creative methods to come up with business solutions and opportunities. The key learning from the case study is that using a collaborative CSR project to incorporate design thinking in B-school helps students to understand and experience meaning and values, concerns and pain points, empathetic thinking, creative thinking, opportunity identification and extrapolation.

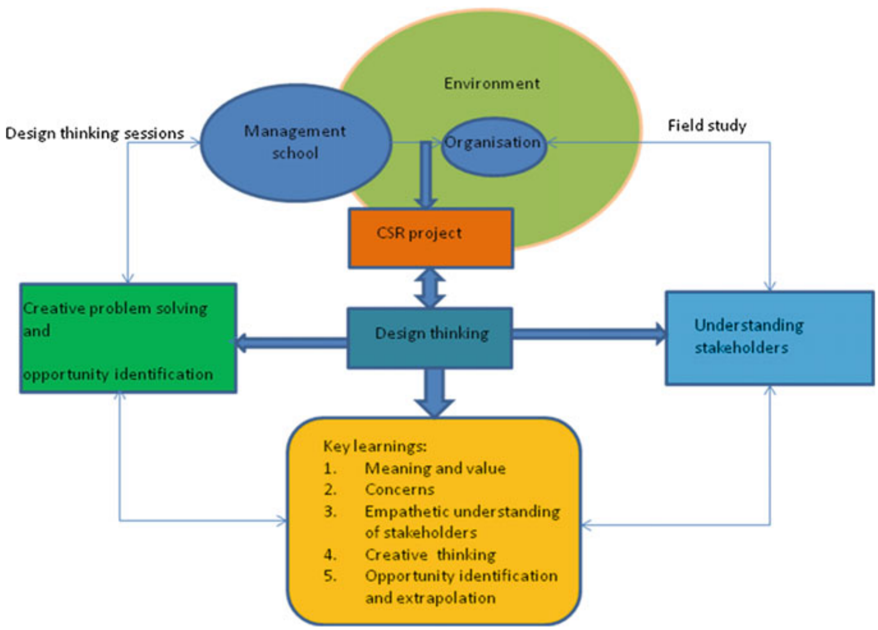

Fig. 2 Conceptual model for introducing design thinking in management schools

8 Conclusion

The proposed conceptual model elaborates the pedagogical approach which can be taken by a business school to enable their students to learn critical aspects of design thinking. Design as a discipline is rooted in practice and as such mere theoretical understanding of design thinking concepts may help in creating awareness about design thinking among business management students but will not help them to internalize the learning and apply them. The proposed model would enable business schools to create a learning environment by broadening the scope of learning beyond classroom through field studies while imparting critical guidance and facilitation through faculty mentorship. It is envisaged that such models would help introduce design thinking in a business school through an experiential manner.

Key learnings on various aspects of design thinking introduced through the case study can help in enabling faculty mentors and guides to prepare course material and inputs. Case studies can be further developed based on projects done jointly by design students, business students and technology students for similar CSR projects and the proposed conceptual model can be further developed.

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Design Research and the Academy: Research Driven Community Facing Work

Diana Nicholas, Debra Ruben, Kathleen Martin and Alphonso Mclendon

Abstract This paper examines the work of community facing faculty research in service to the formation of a new Master's of Science in Design Research (DSRE). A shared core curriculum, diverse faculty research, and existing labs, centers, and consortia, all combine to offer a unique, intellectually stimulating collaborative environment substantiated by a philosophy of investigative research and community projects. The DSRE program is interdisciplinary and evidence-based, with the potential to lead to considerable research and collaboration with other disciplines. DSRE builds on multiple ongoing public interest projects. This design research degree fosters a pioneering environment for cross-college collaborations and community engagement and builds on the ongoing work of standing faculty detailed here. Standing faculty research practices, projects, and the research of industry trends indicate a demand for the fusion of disciplines and inventive, disruptive, an exploratory design that positively impacts the user experience and the environment laying the groundwork for this program.

Keywords Design research education · Community engagement · Participation · Healthy environments

1 Introduction

In the last century, Giancarlo De Carlo published an article in the Journal *Perspecta* that called for design to be participatory. In his article, De Carlo disparages the loss of the users in the design process and calls for the users to be re-integrated. In the process of participatory design, no longer is work created in an elitist fashion by a single predestined originator; instead, produced through the contact that occurs between designer and maker, user and building, audience and artwork, design research is integral to this type of design [1]. The idea of the involvement in such

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work has different and immediate implications for users and practitioners, both. The users of a participatory work engage with the creation of the work, through this engagement they become a part of the process. Here, we examine how community-facing faculty research in service to the formation of this program can create an informed design process that is part and parcel of design research as a discipline. Within a community focused track, which includes environmental design and health, core curriculum, diverse faculty research, and existing labs, centers, and consortiums, all combine to offer a unique, intellectually stimulating collaborative environment substantiated by a philosophy of investigative research and community projects.

The Master of Science in Design Research (DSRE) creates an arena for the consideration of such complex multidisciplinary problems beyond the scope of the traditional boundaries of design disciplines and within the bounds of community participatory practices. ***This program centers on the power of design research in interdisciplinary processes and is an ethical, technological, human-centered, and inclusive toolkit for driving 21st−century design. Students develop a critical understanding of design as theory, idea, and practice in service to global challenges. DSRE is at the leading edge of the burgeoning field of informed design; driven by data, technology, and health.*** High-level learning opportunities through associated faculty research agendas empower students to reframe existing design models for long-term career growth. The field of design research is expanding rapidly at the academic level. There has not been yet established an academic standard to define the discipline [2]. Through careful study of the programs in existence, the DSRE program evolved to address a lack of standard and create opportunities for research to drive the design process. This program creates a foundation for the importance of research in design as a study in creating new knowledge about complex problems. Design research creates the knowledge base necessary to make decisions about the complexity of the world and to build on that store of knowledge, using different information gathering methods, in relationship to the human condition [3]. This, in turn, requires the ability create test and implement the findings from research based scenarios for design. These scenarios must through their development and testing create new knowledge related to human needs, use, and speculations about how that may change based on various systems.

2 DSRE Program: Research in Action

> Scenarios are storytelling tools that present choices and dramatize the impacts of decisions and strategies. They allow stakeholders to access, experience, debate and rehearse multiple responses to possible futures. They are also highly effective prototyping tools that mobilize the imagination and place human experience, behaviors, and motivations— both individual and organizational— at the core [4].

The role of researcher within the creation and planning of today's environments involves processes that have deeper implications for design practice than ever before. Research and design are now intrinsically linked because of the complexity of our current technologies, societies, and environments. A major emphasis of this link between research and design lies in new and existing bodies of knowledge, including cultural study, health, sciences and the humanities [2]. The human use and essence of many spaces must now be carefully considered and developed through research practices both speculative and practical [5]. Metrics and analysis are a major driver in the fields of design. Such developments in making space and creating place arrive at a time when design is increasingly required to respond to the needs of different populations and environments [6]. Research touching on the analysis of human and environmental information drives the discipline of trans-disciplinary design research and the development of the program described here. The works developed include projects that can, and do, embody the findings of analytical processes focused on human use and related to communities. A shift in direction for design, from a more conventional approach to a human and environment research-based approach, Design research allows the exploration of community, participation, and environment.

Scenario building is at the core of the DSRE program and the work described here. The program is interdisciplinary and evidence-based, with the potential to lead to considerable research and collaboration with other disciplines, it builds on multiple ongoing public interest projects. The design research degree fosters a pioneering environment for cross-college collaborations and community engagement and builds on the ongoing work of standing faculty.

The DSRE students will follow a path that includes study with community practitioners and researchers in design and related fields, including health, community design, and public policy. Exploratory and expository Data collection and engaged research practices of design thinking and participatory design are baked into the program. Unlike conventional design processes that take research into consideration, these projects are predicated and driven by, research scenarios that lead the speculative project decision making (Fig. 1).

This area of examination builds on and create innovative health and educational partnerships, economic opportunities and neighborhood initiatives and relates to the strategic mission of the university to be highly engaged in civic sustainability. The program is predicated on cross disciplinary investigation with faculty from other schools including public health, and engineering. The students will build on existing collaboration, and the faculty advisor will work to build and strengthen these collaborations.

2.1 Research, Community and Design Research Pedagogy

> Community design, as a movement, emerged from a growing realization that mismanagement of the physical environment is a major factor contributing to the social and economic ills of the world and that there are better ways of going about design and planning [7].

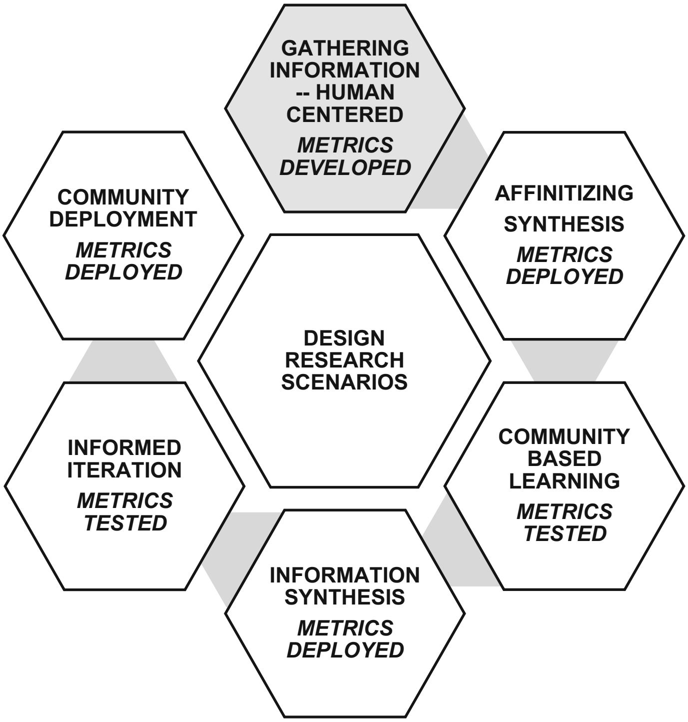

Fig. 1 Design research scenario process in relationship to problem-solving, human-centered considerations and metrics: note iterative design is one of several processes

The community-based environmental health and design research path engages with faculty research. This research focuses focused on assessing and developing design research around the health effect of neighborhood projects near the University's campus where community members face high rates of poverty and lack access to good care. Coursework in this path explores the place of participatory processes in community and design based research around the built environment and health design issues. Design is defined as a set of problem-solving skills including synthesis and iteration the ability to generate many solutions to a problem. It includes the ability to see the connections between solutions to create novel ideas. Design thinking is a problem-solving method that builds on the basic practices of design but includes the gathering of information and novel research through the affinitize-ing and pattern reading of that information [8]. Current coursework in the DSRE program is cross-listed and co-taught between public health and design. These courses often have a specific theme that the public health and design students collaborate on to develop skills in design thinking and ethical design, or "Design with Dignity". Currently, this course is examining the relationship between housing insecurity and health outcomes.

As designers, we often find ourselves in the role of problem solvers and question makers. Design research is moved forward through the process of information gathering and research [4]. The human needs of clients and users are the main conduit for framing design questions. Increasingly the needs of specialized clients require the design of the built environment to reach further and work harder than it has in the past to be accommodating without isolating the user. Standing faculty research practices and projects and the research of industry trends indicates a demand for the fusion of disciplines. Inventive, disruptive, exploratory design that positively impacts the user experience and the environment is the groundwork for this new program. Collaboration between faculty, community and students provide an experience in which participants are learning at all phases of the spectrum of engagement. Learning occurs through interactions with the environment and each other. Built projects, events, and temporary investigations in the urban landscape are all ongoing outcomes. Three overlapping areas of exploration drive these collaborative projects: community engagement, research and metrics related to human-centered needs, and immersion in research-based iteration.

As Sanoff, Margolin, and others quoted here contend; design has changed-research practices can now give designers the ability to transform their processes in an informed manner. Community projects are dedicated to using the urban environment as a resource and laboratory for involved learning: Faculty seeks to immerse all project participants in a rich process that can be mined to affect change in the urban environment through research, learning, and thinking. As such, community facing faculty research anchors the environmental design and health path for this program (Fig. 2).

The overlap in engagement between design, research and community have long been a path towards inclusive community participation. Design research efforts include training community members to collect research data, engage in building their projects, and perceive the urban environment in a different way- all part of successful community participation [7] plans for this inclusive community research

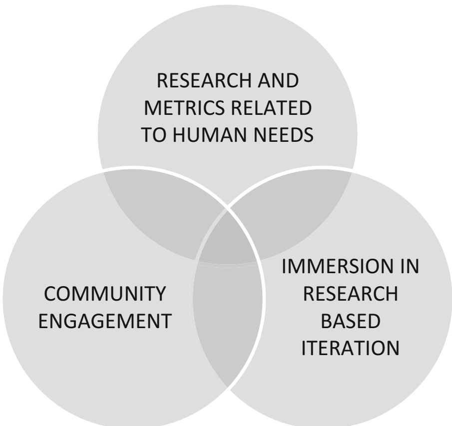

Fig. 2 Design research in the environmental design and health path of the design research graduate program is a product of these three overlapping areas

include side by side education model in which community member and student take classes together, and thus collaborative learning occurs. Cooperative research and community-driven works are ongoing, and MS students will have the opportunity to engage in these efforts. The projects are built on deep experience by faculty and students–these past efforts include playgrounds, gardens, and health assessment units in and around the urban area in which this program is situated. This experience has evolved a design research driven method for deploying in urban communities.

One example of a project in which design research has played an important role is an environmentally driven playground designed and under construction at the Morton McMichael Elementary School in the Mantua neighborhood. Including new greenspace and new playspaces for the neighborhood and school, where there was once a concrete yard, a rain garden provides new sources of shade and seating. In addition, the project creates and new onsite water management system. This project involves participatory work with students at the school, undergraduates, graduates, and faculty. Research topics explored have examined STEAM processes in education. The project has gone far beyond conventional design process to inculcate the three overlapping areas of community engaged design research espoused above. Research engaged iteration has driven the design. Metrics examined include a measurement of activity in existing spaces, measurements for the sun harvesting potential of the site, and a creation of design scenarios that address the ongoing informational research created through engagement with the community.

As part of the playground collaboration, and active research component, public health, and design faculty are conducting a prospective study comparing activity levels before and after the schoolyard development to changes in activity levels in a control school. Students are using the System for Observing Children's Activity and Relationships (SOCARP) [9] method to observe and analyze the children's social play behaviors and active use of playground zones. The boundaries of the zones on the playground were pre-marked by playground structures and vantage points. Observation of the playground took place from the 2nd-floor library. Students recorded observations on a paper form and entered the data into Qualtrics, a digital survey tool used by many epidemiologists. Design faculty and the Public Health faculty have worked collaboratively to develop the methods and procedures for this research project and involved students from both units.

Health, science, and design faculty are also collaborating to examine the effects of green spaces and food production on urban residents. This research-driven collaborative project examines health, built environment and food access for residents. Included in this work are the development of tools for user comfort and sensory needs. There is currently a lack of knowledge on how users are influenced by the configuration and conventional comfort aspects of space, and how multiple factors can increase or decrease their satisfaction [10]. Also well documented are the ways, in a larger sense, that design might respond to those factors. However, few tools exist for designers to quantitatively- or qualitatively-make design decisions based on the comfort of the users, especially users with issues around how they interact with the normal stimuli of an everyday environment this project

Fig. 3 McMichael STEAM playground rendering (*right*) and SOCARP tool (*left*)

considers speculative scenarios for such a tool and works to develop the research context for such a tool (Fig. 3).

3 Conclusion

Students will join MS Design Research program at the starting point of the program, namely the core course sequence. This sequence is designed to expose them to design research methods, data visualization, and high level fabrication techniques. All students in the MS Design research program will engage with these courses. Each student will take an elective sequence that is tailored to their area of exploration and will be chosen with their advisor to complement their interests. The students will also have a three term thesis sequence to develop their thesis in relationship to the are of interest developed in the first year of the program.

The University has an established reputation in conceiving and delivering academically rigorous programs with a foundation in experiential learning that directly connects students to the professions they seek to enter. The DSRE degree attracts a multidisciplinary group of students who will engage in interdisciplinary design research through a shared core curriculum and an individually customized path leading to thesis investigation. The school and university are positions to lead in translational projects that will drive informed design and design research- with a focus on public interest design and engagement. The projects discussed here are vehicles for the students and faculty to collaborate around meaningful, measurable design research and design research outcomes.

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Systems Design is Needed for Smart Manufacturing Curriculum to India

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Abstract In our country, everyone visualizes "Smart" manufacturing and "Regular" manufacturing which belong to different domains. 'Smart' means related to IT domain, not linked with other domains. It is a wrong perception viewed by many of them. The concept 'Smart' is generic. It relates with multidimensional aspects. Before entering into systems design for Smart manufacturing as a curriculum to our Indian students, we must understand the objectives and roles of current trends in manufacturing first. Next, evolutionary systems design of this curriculum will bring social benefits on imparting smart manufacturing to our students. This curriculum brings into a large attention from academics and practitioners of how to best design implement and manage "novelty in manufacturing". This education research evaluates 'General system theory' by K.E. Boulding.

Keywords R&D costs · Smart manufacturing · Nash equilibrium

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1 Introduction

Indian engineering industry has witnessed an unprecedented growth in the past few years as a result of more investment in industrial areas. The engineering industry plays a significant role in the development of other industrial sectors in the economy. This sector is very closely linked with the manufacturing and infrastructure sectors of the economy. The quality and cost of engineering products depends on the quality of the parent machine tools and their automation levels [1]. To improve the Indian manufacturing sector we should enhance the skill level of employees and adopt new methods.

1.1 Manufacturing Sector and Indian Economy

India's manufacturing sector is on a raise over the last few decades. The contribution of manufacturing sector in GDP is 25% by 2025 is targeted by the National Manufacturing Competitiveness Council (NMCC). The current contribution is around 16%. The manufacturing sector contributed 66% to the nation's exports in FY11 and has been strengthening at a Compound Annual Growth Rate (CAGR) of 20% in the last five years [2]. Manufacturing sector is the important component of Indian economy. 12% of India's labour force working in manufacturing industries. The growth in the manufacturing sector contributes to the overall GDP growth over the past few years [2] (Fig. 1).

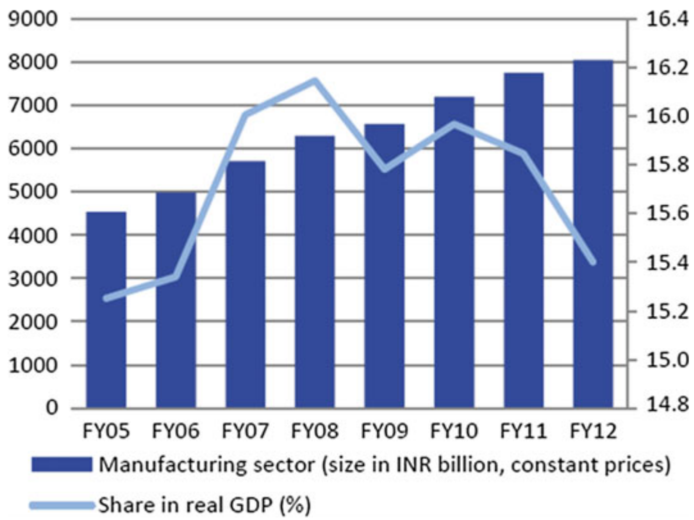

Fig. 1 Size of manufacturing sector in India (*Source* RBI, Aranca Research) [2]

Public sector was the main component of India's manufacturing sector in the past. Private enterprises are the important component now and account for strong growth. India is the largest producer of textiles, chemical products, pharmaceuticals, basic metals, general machinery and equipment, and electrical machinery apart from China, according to United Nations Industrial Development Organization (UNIDO). The Indian manufacturing sector is not only important component to domestic but it also the important component for Global economy. The economic growth of India will shift to a high growth rate of 8.5% in 2020, as per the D&B research [3].

1.2 Current Industrial Growth

The industrial growth in 2012–13 and 2013–14 stood at 2.4 and 4.5%, respectively [1]. Also, there was a growth of 1.4% in gross capital formation in the industry during 2013–14. The Index of Industrial Production (IIP) suggests that the industrial sector is recovering slowly with a 2.1% growth in 2014–15 (April–December) over the 0.1% increase in the same period last year. The recovery is led by infrastructure sectors: electricity, coal and cement. However, the Industrial production grew 9.8% on an annual basis in 2015–16 and IIP growth for September 2015 has improved upwards to 3.84%. As per data released by the Central Statistics Office (CSO), the manufacturing sector, a key indicator of economic activity, grew 10.6% year-on-year in October 2015.

1.3 Manufacturing Sector

The Indian manufacturing sector is facing challenging times. The vision to have the sector contribute to 25% of GDP is critical to achieve, as it is needed to increase our GDP growth and provide jobs- both integral to the inclusive growth. The low growth in manufacturing sector can be attributed to high interest rate, infrastructure bottlenecks, and low domestic and external demand [2].

The core industries in India registered a marginal improvement during 2015–16 (April–February). Coal, fertilizer, electricity, refinery product and cement are done well at that period except Crude Oil, Natural Gas and Steel [4]. 50% of the total investment in infrastructure sector during the Twelfth Five Year Plan (2012–17) is expected to come from the private sector. The infrastructure development is the one of the main concern in Twelfth Five Year Plan for sustaining high growth [5].

The Manufacturing sector has registered a growth rate of 3.1% in 2015–16 (April–December) and the corresponding growth rate in the previous year is 1.8. The manufacturing sector has registered a marginal growth in 2015–16, which shows that it is in the path of recovery and its growth has to be sustained [6, 7].

2 The Potential of Indian Manufacturing Sector

As per Indian Economic Survey 2014–15, "The manufacturing sector in India has the potential to reach USD1 trillion by 2025 and contribute approximately 25–30% to India's GDP" [6]. India has the potential to create approximately 90 million jobs by 2025 as per the survey [6]. India to compete with countries such as China, Germany, Japan and the U.S. in terms of manufacturing contribution, a contribution of 25–30% to GDP is required [8].

The manufacturing output of India can be predicted by mathematical models. One of the way to predict the manufacturing growth is based on the Malthus's population growth model [4].

$$P = Ce^{kt} \tag{1}$$

The population growth is assumed to be an exponential growth. Where P is the population, C, k are constants and t is the time. Using this model we derive manufacturing sector size of India. For this analysis financial year 2005 is taken as base year.

$$M_s = C_1 e^{kt} + C_2 \tag{2}$$

where M_s is the manufacturing output, t refers to the time interval between financial years, C_1 is the constant derived from base year manufacturing data, k is the constant derived from previous years manufacturing data and C_2 is the manufacturing fluctuation. The manufacturing fluctuation based on the world economy, Indian monsoon and the political situation in major countries. Based on our model we forecast the manufacturing size of Indian industry [9] (Fig. 2).

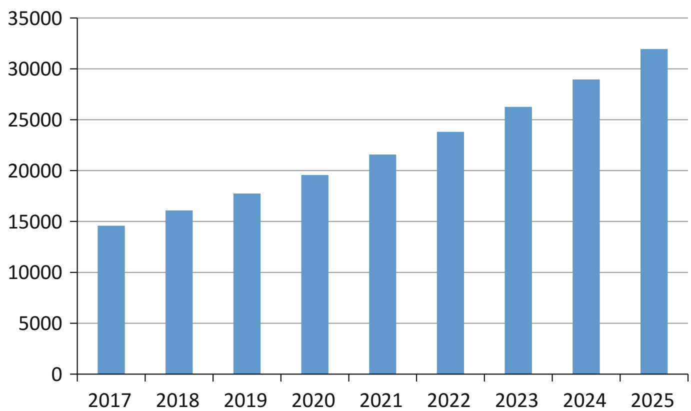

Fig. 2 Forecast manufacturing size in INR billion

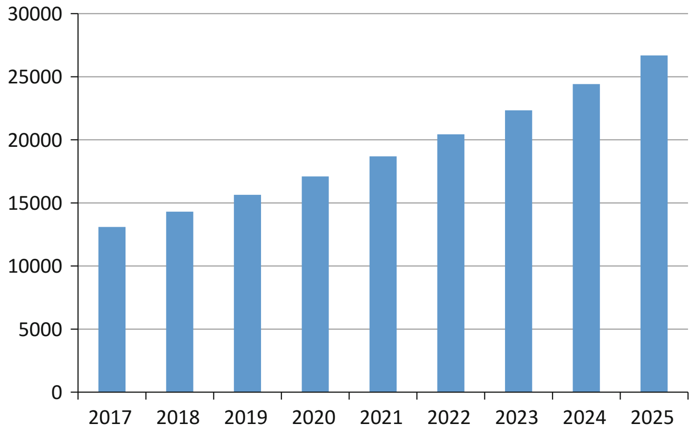

Fig. 3 Manufacturing size in INR billion based on GDP

As per Kaldor's law manufacturing is the engine for GDP growth, and also the raise in GDP have an impact in manufacturing improvement. Based on this law we derived a model to forecast the manufacturing size.

$$M_s = C_1 e^{Gt} + C_2 \tag{3}$$

where M_s is the manufacturing output. t refers to the time interval between financial years, C_1 is the constant derived from base year manufacturing data, G is the constant derived from % of manufacturing in GDP and C_2 is the manufacturing fluctuation (Fig. 3).

The Manufacturing sector accounts for 61.2% of India's total exports in FY2012. The share of manufacturing GDP in India is around 15%. It is low when compared to other economies. The manufacturing sector needs to grow at a higher rate than the GDP growth to capture better share of the GDP [10]. The contribution of Indian manufacturing sector is around 2.2% of the world's total manufacturing output. This contribution is in the region of developed economies like U.K. and France.

In 2020 the top 10 manufacturing companies are United States, China, Germany, Japan, India, South Korea, Mexico, Taiwan, Canada and Singapore. The manufacturing giants of the 20th century (the U.S., Germany, and Japan), hold 3 of the top 4 positions currently and in the future. The U.S. will overtake China to earn the top spot for the most competitive nation in the world, due the country's investment in research, technology, and innovation. A new study on future global competitiveness, by Deloitte Global and the U.S. Council on Competitiveness, predicts that the U.S. will dislodge China as the most competitive manufacturing nation in the world in 2020 [11].

Germany is pushing its leadership in industrial production research and development toward smart production. India will occupy a fifth position as per the forecast has a large population of engineers and factory workers, its intellectual property is widely respected, and it is easy to find English-speaking managers there. The study also suggests that Brazil and Russia seem to have lost their allure as highly competitive manufacturing locations today [12]. Manufacturing competitiveness powered by recent technologies can reduce the gap between digital and physical worlds. The advanced manufacturing facility can serve effectively not only within the factory but also to customers and suppliers.

UK and Canada, emphasizes the ‘back to the future’ theme of these research findings. It also suggests that the BRIC countries (Brazil, Russia, India, and China)—with the exception of China—seem to have lost their allure as highly competitive manufacturing locations today, based on the views of executives responding to this study. India, however, is projected to move back up to the top five in the world, demonstrating executive optimism for the country in the future’.

3 Areas for Improvement

In order to compete or sustain with other Nations India has to dramatically improve the ease of doing business so that many Multi National Companies can start business in India. It should seriously consider single window clearances or at least as many windows as necessary [13]. Government should also make necessary changes in improvising facilities like ports, land, power, access, labour reforms etc. Apart from that the Government should also take initiative for getting highly skilled and resourceful young person by providing proper education to all. The productivity of all sectors in the economy needs to improve so as to keep the prices under control.

3.1 Technology Based Manufacturing and Services

By the year 2020 [14], new and upcoming projects will be driven by the Internet of Things, Big-data, Mobility, Cloud, Virtual Commissioning and Mechatronics [15].

Internet of things is the next big thing for industrial enterprises and is all about being collaborative. The industrial internet revolution is taking place due to the convergence of the automated industrial system with the power of advanced computing, analytics, low-cost sensing and new levels of connectivity permitted by internet. These innovations promise to bring greater speed and efficiency to industries as diverse as aviation, power generation, oil & gas, railways and health care delivery.

These technologies results in zero downtimes, improved profitability, enhanced productivity and optimised resource utilization. By connecting machines to the internet via software, data is produced and insight into the manufacturing process is gained. The interaction of virtual and real production world is a crucial aspect in the manufacturing process.

3.2 Trade Off Between R&D Costs and Improve Manufacturing Capability

It is quiet natural that many companies find some ways to cost cutting. And one of the most common way to reduce the cost is to reduce the costs of R&D. The major concern in reducing the cost is non availability of new products in near future. Instead of that improving the manufacturing capability fetch immediate benefits. As per K.E. Boulding's General system theory [16] a careful trade off is required. Most of the firms struggle to find out a trade off between R&D costs and improving manufacturing capability. The R&D costs [17] and improving the manufacturing capability are the prominent players. If we apply this scenario in Nash equilibrium strategy we will get some suitable answers for the particular firm. The Nash equilibrium theory involving two or more players, in which each player is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing only his or her own strategy [18]. Many companies know their competitor's strategy. Nowadays the nature of market for many products is buyer's market. The manufacturing process and quality of the product based on the market price band. Hence the manufacturers hesitate to take risk by invest in R&D. The investment in R&D for existing manufacturing system has not assured good returns.

3.3 Need of Innovation

The consumer's expectation is increasing day by day. Innovation is the main key to overcome their expectations in terms of quality and cost. The problems raised by the expectation of customers mainly solved by innovation all over the world. The economic growth and standard of living improved by innovative ideas. The gross domestic product (GDP) of China improved over the past few decades due to innovation. The economy of South Korea also improved over the past 3 decades, by encouraging the knowledge investment from foreign and domestic. They also invest heavily in Research and Development. This paper addresses the need for a similar approach for India to achieve higher growth over the coming decades.

There is always a strong correlation exist between innovation and revenue growth at the enterprise level. Global research conducted by PwC clearly highlights this relationship. PwC studied more than 1700 businesses across 25 countries and 30 sectors in 2013 and categorize those organizations based on adaptation of innovation [19]. The parameters are amount spend on innovation, new product launches, co-development work undertaken with partners, etc. This study clearly shows that, the business organizations those invest in innovation perform better than the least innovative.

India's GDP has risen by over 1 trillion USD, and the standard of living is improved for millions of citizens. PwC [19] indicates that the investment in R&D and innovation is essential for India to meet the challenges and to grow its GDP by 9% per annum to become a 10 trillion USD economy over the next two decades. As of 2014, the money spend by India on R&D (0.8% of GDP) is significantly less than its competitors such as China (1.9%), Korea (3.8%) and the US (2.7%). To compete with its competitors and achieve its growth targets India need to increase its R&D spends to 2.4% of GDP by 2034. The amount spends on innovation not only restricted to new technologies and products, but it should also concentrate on innovative processes and business models. The focus on innovative processes and business models improve the growth considerably.

3.4 Skilled Man Power

Skilled man power is one of the main concerns of manufacturing sector. Training the work force for the specific skill set is not an easy task. The need for invest on skilled work force is ever increasing over the decades. To carry out the processes even though they are automated skilled work force is essential. The skilled work force can reduce so many other costs like break down etc.

4 Smart Manufacturing Curriculum

The current curriculum and syllabus for the courses relating to manufacturing sector is clearly describing how to improve the productivity and reduce the waste. It also describes the new manufacturing methods and unconventional machining processes. But in reality, many of the medium and small scale industry's manufacturing methods are thirty to forty years old. They are reluctant to adapt to new manufacturing methods due to investment. Due to the older methods, they are encounter problems like less productivity, high amount of waste and high cost per product. Hence the smart manufacturing curriculum gives input to the existing methods to improve their effectiveness. It may be a small design change or process modification.

Apart from that they are reluctant to spend money in research and development. Even though they now run their industries with profit, in future they will suffer. As per K.E. Boulding's General system theory [16] a careful trade off is required for spent money on research and development. Hence a suitable system design is needed for deploy the knowledge to these type of industries. Regional wise clusters can be formed based on the manufacturing processes and the knowledge required for improving the process disseminated to them periodically. Banathy [20] suggests five reasons why our efforts to make a transition have met with so little success. They are the incremental approach, failure to integrate solution ideas, a discipline-by-discipline study of education, a reductionist orientation, staying within the boundaries of the existing system (not thinking out of the box). All these are examples of "persistence in a mistaken belief," the attempt to interpret current experience using old models and metaphors that are no longer appropriate or useful. Hence a detailed methodology required for disseminating the recent knowledge and models to the industry people and budding engineers.

The smart manufacturing curriculum should have two agendas. One is adapt new manufacturing methods and processes. Second is improving the productivity and cost reduction by making small changes in the existing manufacturing setup. The system should be designed in such a way that it will attract the people who are working in manufacturing sector and deliver the required knowledge to them.

5 Conclusion

In summary, there is a scope for vast growth in manufacturing sector. It is necessary to create a conducive environment to the industry and strong initiatives are needed for the sustained growth. India is an attractive hub for foreign investments in the manufacturing sector. Several mobile phone, luxury and automobile brands, among others, have set up or are looking to establish their manufacturing bases in the country. Technology enabled manufacturing should be promoted to have a cutting edge over other countries. With impetus on developing industrial corridors and smart cities, the government aims to ensure holistic development of the nation. The corridors would further assist in integrating, monitoring and developing a conducive environment for the industrial development and will promote advance practices in manufacturing. India is acknowledged all across the world as a bright spot in the global economy. There is a sense of cautious optimism as the Indian government continues to show intent to undertake structural reforms in manufacturing across multiple sectors. We hope that the initiatives by the Government will act as a significant enabler and provide much needed momentum to steer the manufacturing sector to the next level of growth.

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Infusing Design Thinking Mindset in Engineering Education—A Pioneering Step Towards Excellence and Sustainability

Gagandip Singh Khanduja, Karmjitsinh Bihola and Jaimin Dave

Abstract An engineer must be a problem solver. But today, an engineering education became a business for some avaricious individuals to mass manufacture an engineer. Hence the real practical learning has been washed out from education in engineering and almost all streams. In materialistic world today, every individual wants fast and easy go solution for all kind of problems. Evolution of technological era aimed to make life easy and comfortable for human being, but the sustainability was always overlooked. Design Thinking approach with system thinking, in turn focuses on human comforts and unmet needs of user. It comprises the creative process through which we can get innovative solutions for complex problems. This paper describes the efforts in introducing the Design Thinking mindset across the engineering disciplines at Gujarat Technological University (GTU), Ahmedabad, India. GTU has introduced Design Engineering subject in AY 2014–15 from 3rd semester onwards which is based on Design Thinking approach. To spread the awareness related to Design Thinking as a new approach, University is organizing Faculty Development Program continuously, in 1.5 years total 34 FDP have been organized and more than 2100 faculty members from around 125 engineering colleges across Gujarat state affiliated with GTU has been trained. The paper describes the efforts for implementation and constraints faced, statistical analysis of the feedback for the subjects, pedagogical innovation through syllabus, impact analysis for various stakeholders etc.

Keywords Design thinking · Innovation · Pedagogical innovation · Creativity · Faculty development program · Shift in mindset

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1 Introduction

Design was always a catalyst for innovation processes in product and service development. The old method of using a blackboard for conveying knowledge from a teacher to students is being replaced with an LCD projector. However, this change, unless used with care, may increase the pace of presentation by the teacher, making it more difficult for a student to grasp the lecture fully.

Traditional methodologies of learning and models of professional education may fall short in the changing economic context, said Ellen Yi-Luen Do (Georgia Tech) and Mark D. Gross (Carnegie-Mellon) in their paper on, 'Environments for Creativity—A Lab for Making Things' [1]. Open ended problems should be introduced in the learning with focus on practical learning and skill development as many of the todays education processes may not equipped with tools and methods of converting ideas into solutions. Thus, majority of the academic projects are completed at the ideation stage and not to prototype stage. The Do-Gross paper says that engineering curricula are strong on teaching analysis and principles and light on the actual practice of making things. Design education blended with engineering gives this opportunity of learning to make things and learning to be creative.

As engineering education has become mature, as empirical and analytical processes have become well-defined, the strait-jacket of working out a 'design', using the complete specifications, has become the norm. When one does not look at new materials and at alternative solutions, when one does not consider different ways of solving the same problem, when solving a design problem requires plugging in some values in certain empirical or analytical formulae or into a software package, one does not learn design even though in the class-room an illusion of teaching design may be created.

In reality, a student does not learn creativity or design or the art of making new things, if he/she forgets to look at new materials, contexts of usage and the possibilities of modulating the specifications to obtain a better product. If a student focuses on only the manipulation of the given data to obtain a solution, he/she may earn an engineering degree but he/she may remain innocent of the art of engineering design. "Exploring the alternatives—is what distinguishes routine acts of making, that is to say production, from more creative acts of making that may result in innovative ideas," say Do and Gross. They say that if creativity is crucial in the new economy, then perhaps we can foster creativity by putting making back into education. According to them, there is nothing new about that idea, but for a variety of reasons, learning to make things has become conspicuously absent in most courses of higher education.

It is true that analysis is an important part of engineering studies but learning of analytical procedures can degenerate into study of manipulation of mathematical equations which are devoid of any reference to practical applications of these mathematical formulations. The net result is that engineering education can become boring and purposeless where the four years are used not for learning engineering but for building a transcript, semester by semester and then for acquiring a parchment which certifies that the young person has spent four years at an engineering college.

2 Objective for Development of Design-Based and Project-Based Learning System at Gujarat Technological University (GTU)

Gujarat Technological University (GTU) has started the process of bringing excitement of learning into the laboratories, classrooms and workshops since its inception phase. Besides other initiatives, one strand in the process is to imbue the whole of the learning process, during the under-graduate studies, with design orientation.

GTU is always striving for shaping a better future for its students by putting astonishing efforts to make its education system excellent enough so students and ultimately whole society would benefit. In the light of above context, GTU has established a Centre for Industrial Design (OPEN DESIGN SCHOOL) (Refer concept note [2]) besides with other 13 Centre of Excellence to lead and manage the design-based learning processes at all its affiliating Colleges. On 2nd February 2012 (The first cohort of 4-year degree engineering students graduated out in May 2012.), GTU started the process of updating its syllabi. It was decided to develop a design-based learning system, so GTU has introduced a very new, innovative—Design Engineering subject which is based on Design Thinking Methodology in 3rd semester from AY 2014–15, it is a first of its kind initiation in the Indian Education System.

"Design Thinking is a **human-centered** approach to innovation *that draws from the designer's toolkit to integrate the* ***needs of people****, the* ***possibilities of technology****, and the* ***requirements for business success****.*"—*Tim Brown, President and CEO of IDEO* https://www.ideo.com/about/ (In process branches such as Chemical Engineering and IT, one uses the term 'Project-based Learning' for a similar idea.). A strong 6-semester spine of Design Engineering has been included in the syllabi. At GTU, the processes of designing the project at the Final year and of the spine of Design Engineering, from third to eighth semester of degree engineering programs, have been synchronized in the interest of seamless progression of learning.

3 Implementation Efforts of Design-Based and Project-Based Learning System at Gujarat Technological University (GTU)

GTU-Centre for Industrial Design (OPEN DESIGN SCHOOL) is engaged in motivating design driven innovation at GTU. To move a step forward in this direction, Centre has conducted a series of seminars/workshops to sensitize the design driven innovation intervention via Faculty Development Programs (FDP) at University level. GTU had divided all affiliated Engineering Faculties in Five (5) zones. These five zones are Ahmedabad-zone 1, Gandhinagar-zone 2, VV

Nagar-zone 3, Rajkot-zone 4 and Surat-zone 5; in which colleges are divided by their geographical locations in Gujarat state. During the FDPs faculty members from various branches were invited for the 3 or 4 days programs to understand the Design Thinking process and its value with respect to nearby future. One of the interim statistical analysis reports of the concept shows the beautiful scenario of the thinking process at the University level [3].

3.1 Curriculum of Design Thinking Process at GTU

At Gujarat Technological University (GTU), Design Engineering curriculum [4, 5] is based on globally accepted Design Thinking Methodology. For the 1st year of Design Engineering curriculum the Design Thinking phases may be divided into six simple yet iterative steps shown in Figs. 1 and 2.

The Design Thinking is an iterative process and hence there is always way to re-check problem statement and various components of the same. During the previous year where Students have learnt the detailed Design Thinking methodology in 1st year and successfully gone through the process from Empathy mapping to rough prototypes of their concepts. Now in 2nd year [6] all teams need to take their concept further in the development process of Innovation Value Chain to convert idea into final product/process. At this stage, it is essential to identify parameters and check for five basic design principles viz. (1) Technical, (2) Ergonomics, (3) Aesthetics, (4) Cost and (5) Environment in relevancy to the rough-prototypes

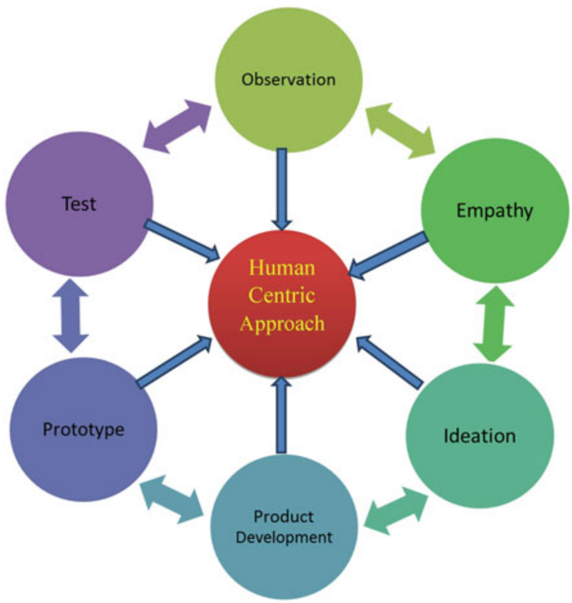

Fig. 1 Design thinking methodology at GTU (based on globally accepted)

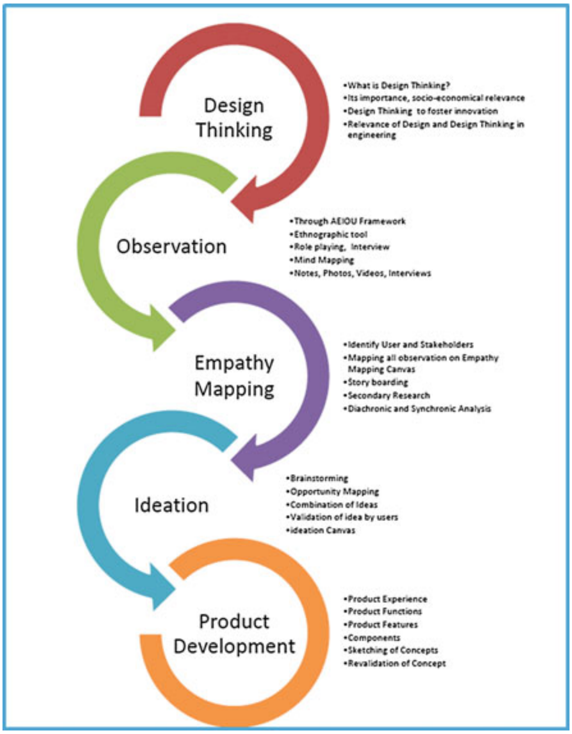

Fig. 2 Design thinking methodology steps to be followed

as developed. Designing something new involves several iterations on different stages/components/aspects. Before investing further resources in terms of time/money/manpower it is important to strengthen these five principles to advance for novelty. Figure 3 shows the path followed ideally towards conceptualization after finalizing the problem statement.

3.2 Statistical Analysis About Faculty Development Programs

Since July 2014 University had organized more than 32 Faculty development program centrally at University level only. During these FDPs approximately 2000 faculty members from various zones of the University had been came across the concept of the Design Thinking process. The sub section focuses on the statistics of the FDPs to make things for visualization purpose to all stakeholders regarding the current position and future planning in regards of subject. The details of the zone wise trained faculty are tabulated in Table 1 and Fig. 4 is plotted for the better visualization of the numbers. The subsection also includes the information regarding the branch specific trained faculty. The details of the same are tabulated

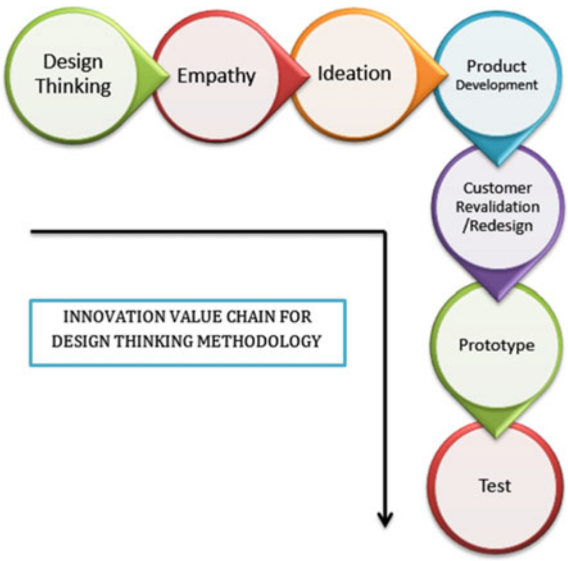

Fig. 3 Design thinking methodology path for conceptualization

Table 1 Numbers of faculty members participated (overall zone wise)

Sr. No.	Zone	No. of faculty participants
1.	I	335
2.	II	489
3.	III	313
4.	IV	206
5.	V	171

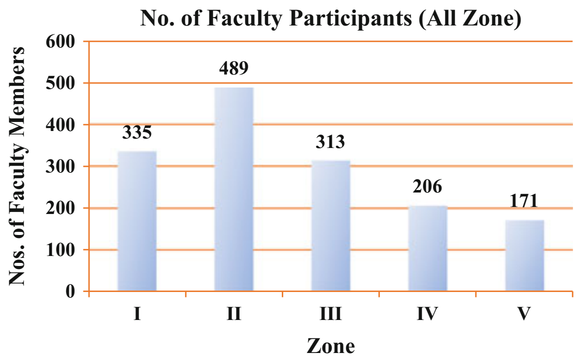

Fig. 4 Numbers of faculty participants from all zones

in Table 2 and Fig. 5 giving overall information regarding trained faculty members in various Engineering faculties. The chart 1 also shows the percentage wise distribution giving scenario of branch specific trained faculty members at University level.

Table 2 Numbers of faculty members participation branch wise

Sr. No.	Branch	No. of faculty participants
1.	Aeronautical Engineering	1
2.	Applied Mechanics	3
3.	Automobile Engineering	37
4.	Chemical Engineering	34
5.	Civil Engineering	240
6.	Computer Engineering	237
7.	Electrical and Electronics Engineering	11
8.	Electrical Engineering	239
9.	Electronics and Communication Engineering	180
10.	Information and Technology	80
11.	Instrumentation and Control Engineering	24
12.	Mechanical Engineering	406
13.	Others	20

4 Overall Feedback and Analysis for Design Thinking Process After Semester Examination

The FDPs of the Design Engineering subject aimed to provide opportunities to faculty members to enrich their idea of systematic design process to solve complex problems through different phases such as Empathy Mapping, Ideation, Product Development etc. At the same time Feedback Analysis is one of the important component to understand the outcome of all the FDPs and the knowledge spread by the faculty members in the class. University invited the Feedback from all the examiner, performed duty during the practical examination of the subject for end semester during Summer 2015 session. During this session total 940 faculty members involved in the external examination work. The analysis of the feedback helps in understanding the real scenario of the subject at the Institute and overall at University level.

The various questionnaire have been asked to know the learning process among the students and within the institutes as mentioned below. The ratings of the questions were decided based on scale of Strongly Disagree, Slightly Disagree, Neutral, Slightly Agree and Strongly Agree selection. The overall responses from all the examiners is shown in Fig. 6.

The set of questionnaire asked for feedback analysis as below:

1. Whether the students understood the design thinking approach properly?
2. Whether the student groups performed AEIOU framework during field observations during Empathy Process?
3. If students came up with multiple solutions based on Ideation process after applying Design Thinking to their problem statements?

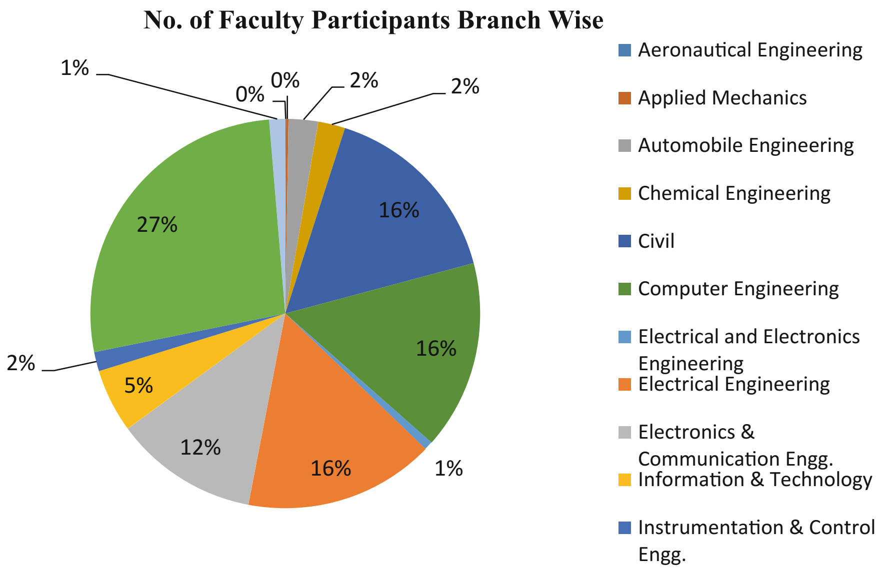

Fig. 5 Percentage numbers of trained faculty members branch specific during FDPs

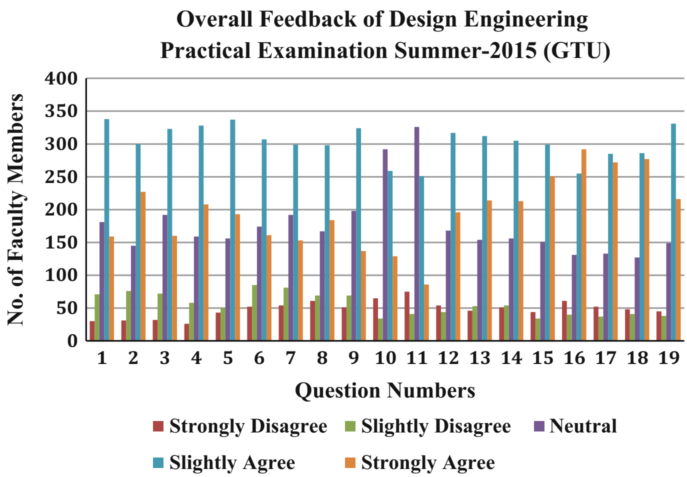

Fig. 6 Overall feedback of design engineering practical examination Summer-2015

4. Whether Students' thought process and thinking capabilities improved due to this canvas/framework based exercise and implementation of Design Engineering?
5. Did the perspective of students for their problem have been changed after observations (AEIOU framework) in DE-1B course?

6. Did the Learning Need Matrix (LNM) prepare by students with the help of teachers clearly understood by students?
7. Whether the prior art search performed by students is satisfactory to improve Novelty of Project?
8. Whether the fast prototypes/rough models/diagrams prepared by the students satisfactory?
9. If the quality of the reports describing various processes prepared by the students satisfactory?
10. Which was the most useful canvas/framework among the Students?
11. Which was the most difficult canvas/framework among the Students?
12. Even if the overall teaching of the subject is satisfactory in context of amount of duration provided in the teaching learning process in the college?
13. Even if the overall teaching of the subject is satisfactory in context of syllabus content delivery?
14. Even if the overall teaching of the subject is satisfactory in context of quality of the learning Environment during delivery of the course?
15. Whether the Design Engineering Subject was included for continuous three hours in the timetable in hands on mode?
16. Whether the trained faculty members at GTU in Design Engineering have taught the subject in all classes in college?
17. If the trained faculty members in Design Engineering have Co-Guided the final year (IDP/UDP) projects for their design component satisfactory?
18. Whether the understanding of internal faculty/guide trained at college level was adequate for this subject?
19. In your overall Examination, whether the performance of the branch/institute was satisfied?

5 Conclusion

Design Thinking is currently sizzling topic and everybody realizes importance of the same with prospective of innovation via Design Thinking in nearby future. Education institutions are now establishing curriculum specially based on Design Thinking and its future outcome advantages. Design Thinking is a powerful methodology that can benefit individuals, economies and societies; it helps apply multiple viewpoints to a problem. At Gujarat Technological University very rich potential is available looking at the affiliated institutes and various engineering faculties. In real sense implementation of such thinking process can achieve dream of “Make in India” true in real sense. As well-wisher of nation, GTU introduced subject in curriculum to all engineering faculties of the affiliated institutes to overcome repeated problem statements and solutions of the same by Students-Faculty members and to find out real unique community challenges as problem statement to solve the same in upcoming time. As per the feedback analysis, the canvas based exercises are most suited for mass education of Design Based Learning which will create the co-creation among the students and they will learn the team work. Observation tends to prove the most significant and important phase of design process as it would help to find the unmet needs of user as well as to clarify the problems in better sense.

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Rigid Frames and Flexi-Frames—Matchstick Cellular Space-Frames Hands-On Self Realised Learning Approach

Ranjan De

Abstract In our present education scenario, whether it be schools or design schools, the pedagogy gives no room for self-realized and empowered learning approaches. The Rigid Matchstick Spaceframe and the Flexi Matchstick spaceframe approach to exploring both the internal geometry and what happens to the surface of solid geometry is being presented here. The development of affordable geometry pedagogy, by using matchsticks, a material turned tool—to create rigid and flexible spaceframes. The created spaceframes are used as space analysis tools to further create new 3D surface solids. This then empowers the learner to explore surface solids and create new nets, new solid forms and hands-on 3D visualisations. The paper expounds the pedagogical impact, the assessment methods developed and further explorations and methods that this approach can go towards, and it is a study of a work in progress.

Keywords Space-frames · 3D geometry · Internal geometry · Analytical tool · Cellular structures · Rigid frames · Flexi-frame · Space analysis · Matchstick structures · Creating original nets · Geometrical construction · Hands-on self realized learning · Optical precision · Patience · Perseverance · Stress testing · Affordable tool

1 Introduction

It all started at the Shristi School of Art, Design and Technology, in 2002. The target audience was the 1st year Foundation students and the course was on 'Visual Perceptions of Ambient Space'—another approach to basic Human perceived representational drawing of space and objects in relation to each other. The interesting feature of the Aditi Mallya Senior school building is that the roof fiber panels

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Fig. 1 Shristi school of design. Yelahanka, visual representation of the roof space-frames

are supported by a series of space frames, and the load bearing roof pillars are few and far between, leading to an interesting uncluttered spatial structure (Fig. 1).

The students tried to perceive that space frame above their heads and to visualize and draw the same in 2 point perspective. After a point, most of them just gave up as they just couldn't visualize it. The students who were finding it especially tough to perceive the overlapping members of the structure of the roofing spaceframe, were requested to get a pair of boxes of Home-light Matches each and a small tube of Fevicol poly-synthetic adhesive.

They were then asked to replicate the roof space-frame, with the matchsticks. The scale model on a grid of 4 × 4 squares helped them perceive what was happening, and also perceive where the invisible members of the structure were hidden, they tried to represent the same. The scale model of the space-frames that they had created with the matchsticks—with the chemical removed from the heads of the matchsticks, aided their visualization of the structure and thereafter helped immensely in their 1 point, 2 point and 3 point perspective drawings. A new and cost effective tool for perspective visualization had been created.

The interesting deduction from then on was that this process could be a useful low-cost tool to aid perceptional pedagogy of human perspective representation of space, as not all design school campuses or educational institutions have the privilege of access to outdoor spaces.

The students were interested in seeing where the matchstick model making could go, and so was born the basic idea that matchsticks could be used as a tool to look at the internal geometries of the Platonic and Archimedean surface solids that are so often taught in school and primarily in the Foundation studies of most design schools in India. The norm to this pedagogy changed at this venue with this exercise, as from now on, even the internal cellular geometries of the Platonic and Archimedean solids could not only be studied, but the structures understood and harnessed to aid applied geometrical learning. The present pedagogy even though using matchsticks as a tool, imitates the study of just the surface planes of the geometric solids and not the internal cellular structures—that support the skin.

2 The Preparation Process for the Matchstick Geometry Structures

The participants of the process of creating these geometrical structures, are lead through a step by step process—from sorting out the matchsticks to the level of precision in terms of heights of each matchstick and how that would affect the construction of the overall matchstick cellular spaceframe structure.

The students first acquire the 2 large Homelights match boxes with 200 matches. As matches are mass manufactured—and thus not made specifically for precision model making, the students are shown a process from where they can sift the good ones from the bad ones. All participants start with the basic units of four of the cellular structures to be explored—The tetrahedron, the square based pyramid, the triangular prism and the cube.

Once the sorting of the matchsticks has been done by twirling each matchstick between the thumb and index finger to see the straightness of each matchstick, the chemical heads are removed by scraping the same off with a paper cutter. This is to ensure that the structures that are finally constructed do not get distorted and retain structural precision.

The required number of matchsticks needed for an overall project are processed, and have to go through one more final test to check if they have truly made the grade for the match stick space-frames to be constructed.

The matchsticks are aligned against a steel scale, or a glass sheet that has a sharp, uniform edge. Here the 200 or so matchsticks that would be needed for a final large scale space-frame construction are lined up, in rows, to check if there are aberrant matchsticks that have escaped the eye, and these are finally weeded out, so that only the best make it to the construction. The tolerance between the height of the sticks are not to exceed one optical millimeter.

2.1 The Actual Processes and Learning from the Creation of the Cellular Spaceframe Structures

Once the raw material is ready, the process of creating the 1st cellular structures of the 4 geometric solids starts. The participants are told how many sticks will be used for each basic unit structure—Tetrahedron—6 sticks, Pyramid—8 Sticks, Triangular Prism—9 sticks and the Cube—12 sticks—a total of 35 sticks, with 5 sticks as standby.

The diagrams in plan and elevation are shared as a reference point, and the students are told that they must themselves figure out the construction of these basic space-frame units. What has been observed over these 15 years, is that this is where each student's own approach to self-discovery starts, even while building these basic units geometrical space-frames. The students are made aware that it is not the adhesive that will hold the structure up, but the nature of the structure itself, and minimal adhesive may be used, just to hold the component matchsticks together in the framework. Even from this initial construction of the basic units—the students learn the 3 Ps that will empower them for the challenges to come—Patience, Perseverance and Precision.

2.2 The 1st Stage Learning After Construction of the Cellular Structures of the Units

The process goes from the simple units, to the more complicated cellular internal frame works of the 1st two solids—Tetrahedrons and Pyramids, as they are the most popular in the sphere of building space-frames, especially within the time constraints that most campuses allot for this input: two weeks, exclusive of weekends. Depending on the time frame allotted, the students with build a 3 × 3 unit Tetrahedron cellular space-frame and also construct a 3 × 3 unit base pyramid or a 4 × 4 unit base frame. The base unit of the Tetrahedrons, are triangles and for the pyramid cellular structure it is squares (Fig. 2).

While the students go through the construction of these spaceframes, they realize that they are going through a very stringent process of quality construction and they experience the 3 Ps: Precision, Patience and Perseverance, at every step of the process—important qualities that will see them through many daunting design challenges to come—in their careers ahead. But there is also an element of play added to the pedagogy here: the fact, at any given point the students have to keep cross checking that all the struts of the structures are always in proper alignment.

The completed Space-frames look like this, when seen from above (Figs. 3 and 4).

Fig. 2 Student constructing the 1st level of a 4 × 4 of a 3 level truncated pyramid matchstick spaceframe

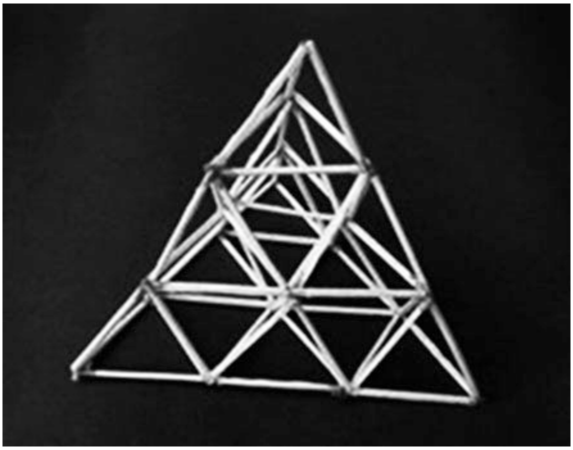

Fig. 3 Tetrahedron even cellular matchstick spaceframe

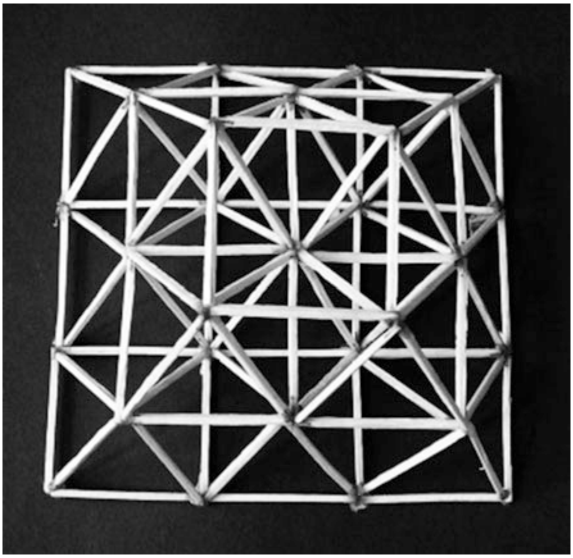

Fig. 4 Truncated pyramid even cellular matchstick spaceframe

3 2nd Stage Learning—How These Matchstick Space-Frames Can Be Used as Tool

Once the students have created the Matchstick space-frames, another lot of exploratory exercises present themselves—why they were making these space-frames and if they have any use at all? This was the offshoot of a student's query.

One of the first explorations, a task that many students take to with bated breath, is the tile/brick stress tes. Each of the matchsticks weighs 1 g. A standard building brick weighs between 2.5 and 3 kg approximately. The 4 × 4 grid base pyramid space-frame, truncated at the top to aid a 4-point landing when upturned, can hold this brick, if gently placed, keeping in mind the center of gravity of the structure and the brick. If the space-frame is well constructed and all the matchsticks at every node well placed then, the load of the brick is taken on easily, beyond, 20… 30… 60… 90 s… and if the structure is perfectly constructed—the structure can bear weight for minutes. The moment the student realises that their structure can take the weight of that tile, is one of exhilaration, indeed a moment of triumph. A few though, in the hurry to complete their task, and cheered on by peer pressure to opt for the tile test—fail to experience this as they see their hard work gently collapse before their eyes.

There is a huge moment of learning here for the students. They learn with quick immediacy that every matchstick has a role to play in keeping the brick up, and indeed so does every joint in the structure which takes the stress from the many points on the surface, and how each point passes on the stress to the next, till at last the 4 points on the supporting surface of the table, carry the load of the brick from each of the upper nodes with ease, if the structure is precise and perfect. But, if even one node or any of the stress bearing points have not been placed well, or slip by a millimeter, the entire structure shears at the dynamics of the weak node or a weak matchstick, and collapses. This experiential learning is initially intuitive, but on study of where the matchstick spaceframe collapsed, makes realization dawn—which no theory can ever make them realise so implicitly. The brick or tile test is one of the tools of assessment of the structural strength of the construction, as well as the precision and accuracy of the construction of the spaceframe.

Not surprisingly, this actually encourages them to construct the collapsed matchstick space-frame with more vigour, speed and precision to match up to their peers, and in the 2nd innings, some have even managed to place 3 such concrete paving tiles/building bricks—a 9 kg weight on a matchstick spaceframe construction using only 196 matchsticks, so a power to weight ration of 196 g versus 9 kg, kept aloft for over 30 min—the duration of a jury panel—an incredible feat by any standard. This approach to assessing each student's precision model-making skills, also assesses their basics of physics of stress bearing structures, and makes them curios for further enquiry into this. It has been observed time and again, that students—both UG and PG—and specially structural engineering graduates—state that this process opens their minds to how these spaceframe structures really work, and how, if well constructed, can combat shear and yaw movements in load bearing structures. They also realise why such structures are used in the construction of aircraft hangars, bridges, airport lounges, large scale auditoriums and sports stadia and exhibition pavilions. At the end of even this 1st process of matchstick cellular spaceframe geometry, their minds have been ignited with a plethora of ideas (Fig. 5).

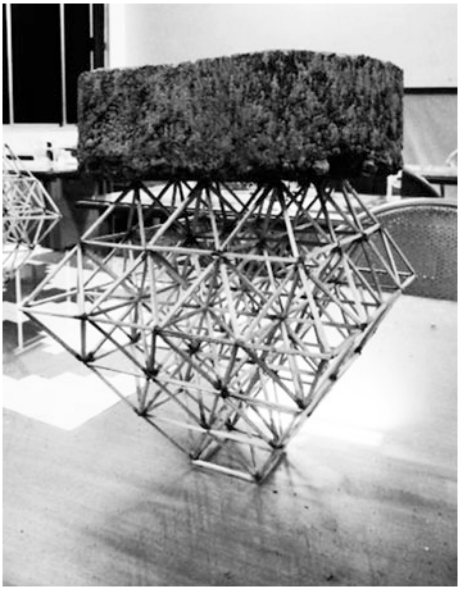

Fig. 5 196 g versus 3 kg—the power of a well—constructed load bearing matchstick cellular space-frame

3.1 The Creation of Interlocking Geometric Puzzles—Creating Original Nets

The next stage of the application of the tetrahedral or pyramidal space-frame that the students have created, is that it can be used as a space analysis tool, so that it helps each student create a 8–12 piece interlocking puzzle of surface solids. They understand the internal planes of the overall solid and it helps them figure out how to make interlocking solids, that finally form a composite whole.

What the students learn during the process of constructing each unit of the interlocking surface solids is, the efficiency of creating their own nets, and the precision required to do the same. The students also learn aspects of net and joinery rationalization, so that the construction of each of their 3D surface forms can be done easily, if ever the surface solid structure has to go into mass manufacture. The solids do not use adhesive to form the 3D surfaces, but are joined together with tongue and groove approach to construction, and if creased and scored and done with care, the solids are good examples of 2D shape to 3D form transformation. The students learn that adhesives are not necessary to stick or form surface solids, and if the geometrical construction and cutting is precise, the finish is better than one stuck with adhesives. This thinking can be applied to varied applications in manufacturing and construction of everything from packaging—as it aids collapsibles and flat pack construction—not only with paper boards, but with other materials and processes too—to architectural forms and even to flexible envelopes, earthquake shelters and emergency enclosures (Figs. 6, 7 and 8).

Fig. 6 The truncated pyramid as an internal space analysis tool for creating forms for an interlocking pyramid puzzle

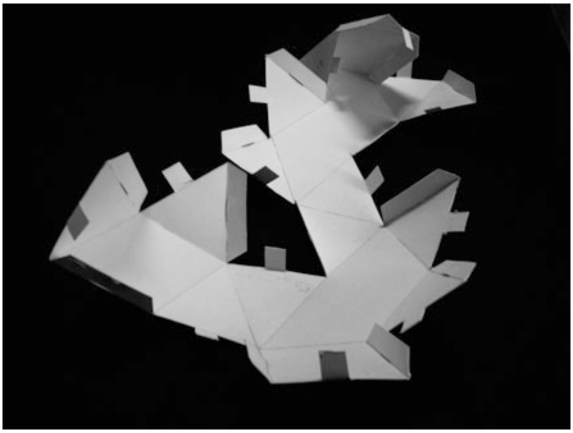

Fig. 7 An original schematic of an open net of one of the components of a solid surface pyramid puzzle

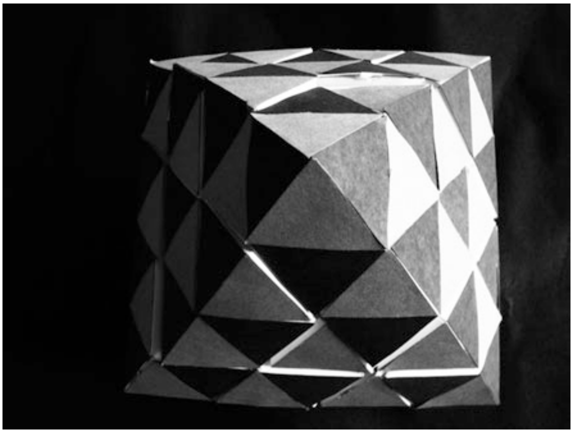

Fig. 8 The plan view of a completed assembled pyramid puzzle

4 How Did Flexiframes Evolve?—3rd Stage Learning and Evolution

The flexiframes was something that was just chanced upon, as many of the best innovations normally are. A student while constructing a 3 × 3 grid cellular spaceframe of the Tetrahedron forgot to place the in between struts that gives this structure its structural rigidity. When the adhesive dried overnight, and when the topmost node of this new structure was pinched, one discovered that it transformed with an amazing plasticity. And that was true of any node that could be pinched or even tucked in. When the student constructed a twin tetrahedron structure there was a possibility of how two nodes at the two extremities would respond based on how intense the pinching on the nodes were. Over the past many workshops in Design and Architecture schools, the Flexiframe and its intuitive and real time learnings

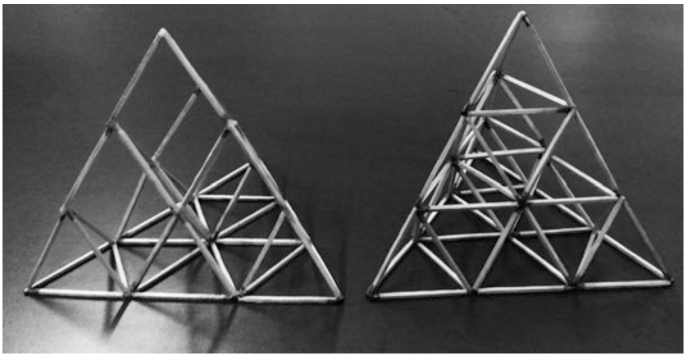

Fig. 9 The structural difference between tetrahedron matchstick cellular flexi-frame and the rigid frame

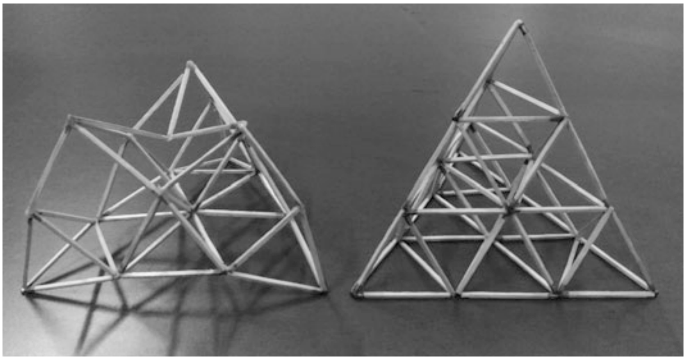

Fig. 10 Tetrahedron matchstick cellular flexi-frame flexed to show how it reacts to surface and nodal manipulation

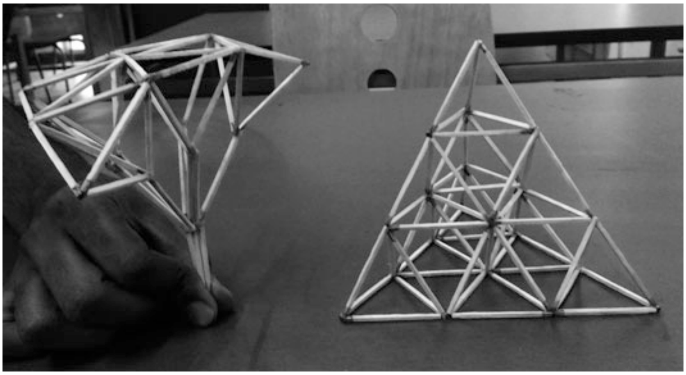

Fig. 11 Tetrahedron matchstick cellular flexi-frame extreme pinched to show how it reacts to surface and nodal manipulation

have been incorporated into the main curriculum. Increasingly, this workshop is gaining popularity in exploration of the cellular spaceframe structural within schools of architecture pan India, under the ambit of light weight structural load bearing spaceframes which even though they are flexible, can handle shear and yaw aspects of lightweight structures (Figs. 9, 10 and 11).

5 Learnings and Conclusion

5.1 Why It Is Such a Fantastic System of Self Realized Learning

The process along with co-creation efforts of students across many schools, training centers, NGOs who have facilitated this approach to applied geometry, solid geometry analysis have lead to its continual development as a self-realised approach and a resource, and it is very much a work in progress.

The fields that have been explored so far include flat pack disaster shelters, flat pack sans adhesive furniture, luminaires, mannequins, space saving architecture, freestanding spans and bridges with unique load bearing geometries. It has also been used in corporate training to train HR managers the pros and cons of the Pyramid structure of hierarchical management vs the matrix structure of the new management. It is a great tool to teach 2 point and 3 point freehand human perspective representation, too.

As a tool and approach for learning, especially within the yearlong Foundation format in Design schools, most students have had the highest recall value of this input, and they believe the latent learning can be and has been used many fold, across their careers.

The biggest advantage one has understood in this system is that, it not only goes way beyond just empowering the student with approaches to self reliance in terms of structures, but also self-reliance in creating nets and original geometry based solid forms.

The many groups of students in batches of 20–50 who have co-evolved this process, have all also drawn to the conclusion that the process from the sorting of the material to be used, to the creation of the matchstick spaceframes as an internal space analysis tool of geometric solids to create unique interlocking 3D puzzles—2700 of them to date—each distinctively unique from the other—has created a body of work and a pedagogical approach of empowered learning that further needs to be studied to analyse its true impact.

Throughout the last 15 years of exploring this workshop format it has been concluded that Matchsticks are a universally available tool and learning material. A huge plus point of this approach has been that a lot of students who previously had a dislike towards mathematics and geometry, have actually started to passionately love the subject. And to quote Ex President A.P.J. Abdul Kalam, here is a set of tools and processes that can inculcate math-magical and geometrical spirit, instill and trigger curiosity and enquiry and “ignite minds” and scientific temper—all with the help of a simple box of matchsticks and minimal adhesive.

Acknowledgements There have been many supporters on this journey of discovery and I must acknowledge my many hosts at the Design and Architecture School campuses across India, who over 14 years have hosted me and believed in this approach to creativity, using these humble matchsticks to empower young minds to greater creativity through self realisation.

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A Novel Frame Work of Design Realization Course at IIITDM Kancheepuram: Critical Evaluation

Deepak Ranjan Padhi, R. Adeline Mellita and M. Sreekumar

Abstract Consistent evaluation and analysis of academic courses is a good practice in order to make the content more relevant to the current needs of industries and academia. In this work, "Design Realization Course" at IIITDM (Indian Institute of Information Technology Design & Manufacturing) Kancheepuram, which is a part of the novel curriculum, framed for the undergraduate engineering studies, is taken as the subject for critical evaluation. A thorough user study is done for 6 months using contextual inquiry and questionnaire methods. We report findings of a survey that investigates how a design course is taught in a technical institute, its limitations and scopes. In order to validate the interpretations a comparative study is made with other reputed design schools. Some of the key findings are that design courses need to emphasize on hands-on way of doing things, students perform better if they are given more time and flexibility and so on.

Keywords Design skill development · Design realization process model · Contextual inquiry · Heuristic evaluation · SWOT analysis

1 Introduction

The Design realization course at IIITDM Kancheepuram helps students to enlighten the creative side of their engineering skill sets during their undergraduate studies. Today, in industries, importance is not only given to technology optimization, but also much emphasis is given on user study, usability evaluation, interaction design

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and design optimization. Product design is a goal driven problem solving process that blends engineering knowledge with creativity in design. This requires professionalism, interdisciplinary skills and knowledge of software and hardware tools. To develop these traits, learning by doing is very important. Hence, the students are exposed to different labs where 'Design Realization Lab' is one of them. Here, the students learn the concepts of product design, product evaluation and model-making using various interactive methods. The course has been designed in such a way that the students learn to prioritize functionalities, process exploration, design aesthetics and quality of implementation. However, the course should be consistently evaluated to best enhance students learning according to the current design trends. It is also helpful in understanding the limitations of the program.

This paper is organized as follows. Section 2 discusses the course structure and course objectives for both theory and lab courses; Sect. 3 presents the methodologies adapted for course evaluation; Sect. 4 shows the statistical analysis done based on the qualitative and quantitative data collected; Sect. 5 deals with the SWOT analysis performed and Sect. 6 concludes and states the future work.

2 Course Structure and Objectives

The primary purpose of a syllabus is to familiarize, what the course is about, why the course is taught and what are the efforts and skills required for a student to complete the course with a passing grade [1]. Therefore, the syllabus should be structured in such a way that the coursework can become clear and easily understood by everyone including those who haven't opted for the course. Optimally, the course syllabus should also generate interest and motivate students to excel in the course and to continue to the next level.

In order to provide the complete knowledge of design basics and processes, IIITDM Kancheepuram offers both theory and practice courses on Engineering Design and Realization exclusively to the 1st year undergraduate students of all disciplines (Mechanical, Electronics, Computer Science and Dual Degrees).

2.1 Theory Course: "Concepts in Engineering Design"

The objective of this course [2] is to introduce the fundamental principles of Engineering Design which is very important and relevant in the context of engineering requirements today. The course is generic to all engineering disciplines and does not require any specialized prerequisites. Case studies and product illustrations are used for better understanding and enhance learning.

The contents of the course [2] are listed below.

- Design conceptualization and philosophy, Original, Adaptive, Variant and Re-Design, Evolution of Concept, Need for Systematic design and Past methods of design
- Product life cycle, Innovation, Types of innovation
- Needs and opportunities, Vision and Mission of a concept, Type of needs, Technology S-curve, Need analysis, market analysis and competitive analysis, Kano Diagrams, SWOT analysis
- Conceptualization techniques—Idea generation—ideation, brainstorming, Trigger session Brain writing, Mind maps, SCAMPER (Substitute—Combine—Adapt—Modify—Put to other use—Eliminate—Rearrange), TRIZ (Teoriya Resheniya Izobretatelskikh Zadach—in Russian acronym) [3], Biomimicry, Shape mimicry, Familiarity matrix
- Concepts screening, Concept testing—exploratory tests, Assessment tests, Validation tests, Comparison tests—Case studies
- Organization of design concepts and design methods, Engineering Design—Descriptive and prescriptive model, Design decisions and development of design
- Group work and case studies.

2.2 *The Lab Course: "Design Realization"*

The course objectives are listed below.

- To realize the concepts through a systematic problem-solving methodology
- To encourage teamwork
- To improve idea generation by using design principles
- To constructively combine ideas rather than criticizing
- To practice efficient use of design tools for model making
- To have hands-on practice with design exercises and model-making leading to realization of a new product design by the teams.

The contents of the course are listed below.

Exp: 1 Concept selection and model making of simple objects—Plastic model
Exp: 2 Concept selection and model making of simple objects—Sheet metal model
Exp: 3 Clay and Foam model
Exp: 4 Idea generation using SCAMPER, concept screening and design realization
Exp: 5 Adaptive design
Exp: 6 Need analysis and realization
Exp: 7 Morphological analysis and realization

Exp: 8 Concept generation and model realization—TRIZ contradiction and principles
Exp: 9 Modular and integrated architecture—Aesthetic design
Exp: 10 Product dissection and re-design.

3 Methodology of Course Evaluation

Course evaluation has been done using library research such as analysis of historical records and analysis of documents in the literature [4]. This work has been improved by using field research such as participant observation, mass observation, personal interviews and focused interviews [5]. In the present work, user study has been done employing contextual enquiry and questionnaire method.

For each experiment the students follow a general model which is shown in Fig. 1. In the 1st stage, ideas are generated using different design principles such as SCAMPER, TRIZ, Morphological analysis etc. In the next stage, the concepts are evaluated using multi-voting method, benchmark matrices and Pugh charts followed by final sketching and product realization using different materials such as thermocol, clay, plastic, thin metal sheets etc. in the last stage.

The course evaluation has been done by collecting data from students, instructors and TAs (teaching assistants). A total of 110 students have been interviewed with questionnaire method and with scheduled and non-scheduled interviews. Similarly, the feedback has been collected from six teaching assistants and two lab instructors. Contextual inquiry followed by heuristic evaluation has been done by borrowing the knowledge from ethnographic research methodologies [6]. The data is recorded digitally and visualized statistically in the form of graphs and charts. The course is evaluated by focusing on the parameters like course structure, course organization, lab resource availability and utilization, qualitative and quantitative analysis of each experiment, student's performance, students' delight and creativity analysis.

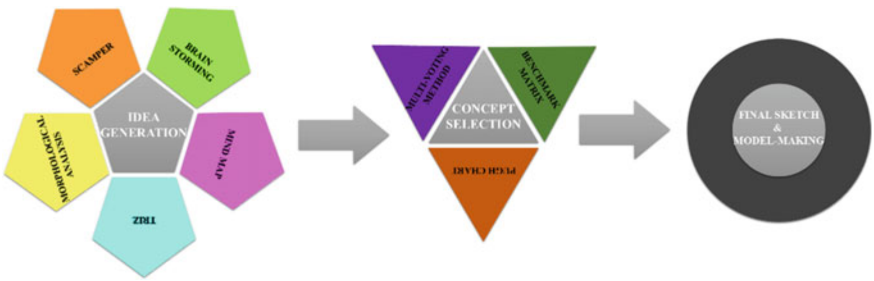


Fig. 1 Design realization process

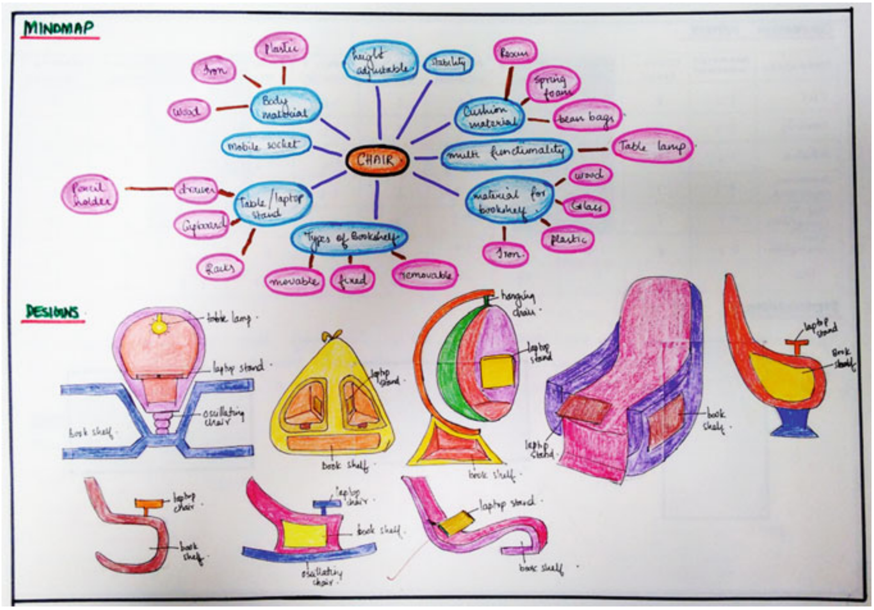


Fig. 2 Integrated design models

A typical image of idea generation and sketching made by a student is shown in Fig. 2. Models designed using TRIZ principles are shown in Fig. 3. Products realized using thermocol and clay are shown in Figs. 4 and 5 respectively.

4 Evaluation and Analysis

At the beginning the students are observed and interviews are conducted to understand their conceptual models about the course and its objectives. A detailed questionnaire is then prepared based on the focused parameters. Some questions are also asked to evaluate the merits and demerits of interdisciplinary course structure [7]. The statistics are shown in Fig. 6.

It is found that 47% of the students are satisfied with the course structure and 8% of the students are highly satisfied. 30% of the students have opted to be neutral. Only 15% of the students are observed to be unhappy with the course structure. Interviews and contextual inquiries are performed to understand the underlying problems. The issues are found to be, insufficient time to finish the experiments, clubbing of various tasks in a single experiment and a repetition of few concepts. Few students are also not happy with the interdisciplinary concepts.

As far as the course organization is concerned, it is very much important to support the course structure. It deals with the sequence of experiments which

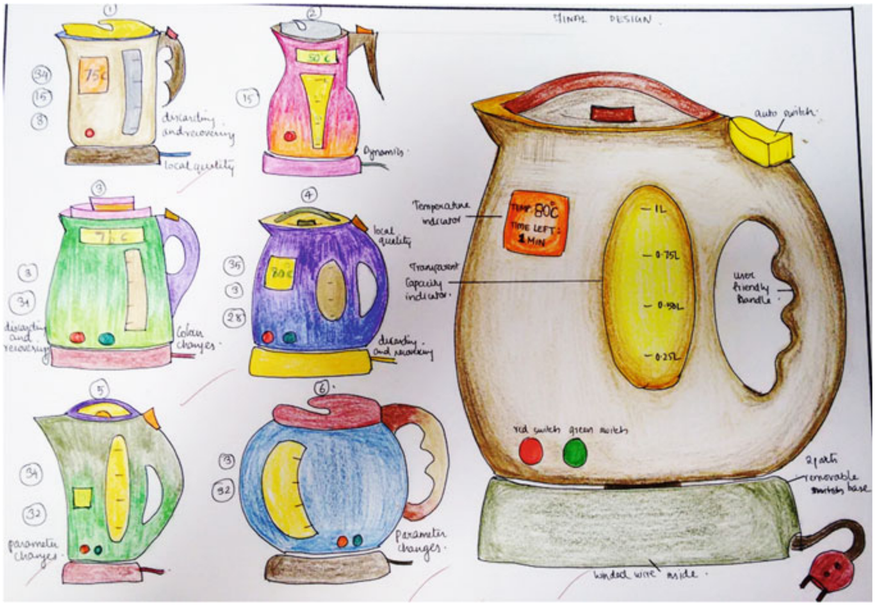
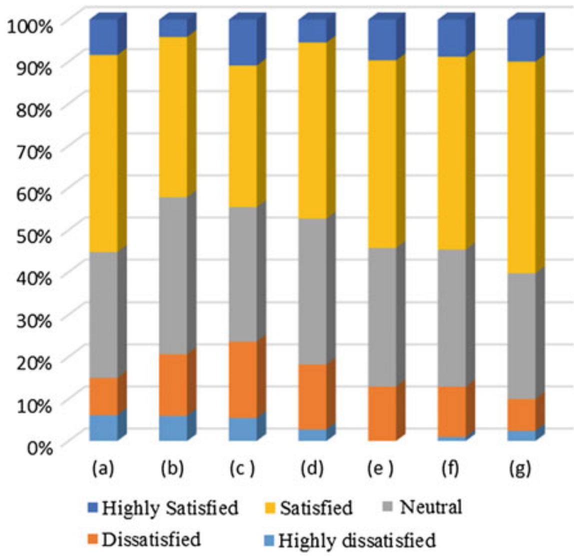


Fig. 3 TRIZ modelling of electric kettle

Fig. 4 Thermocol models

Fig. 5 Clay models

Fig. 6 Graph between students' satisfaction levels with course defining parameters. (*a*) Course structure, (*b*) course organization, (*c*) availability of lab resources, (*d*) qualitative analysis of each experiment, (*e*) skill development, (*f*) students' delight, (*g*) creativity analysis



support the gradual understanding of concepts. It also deals with the quality of materials and handouts provided to the students. As per the survey, 42% of students are satisfied with the current course organization. Only 10% are dissatisfied and 37% have opted to be neutral.

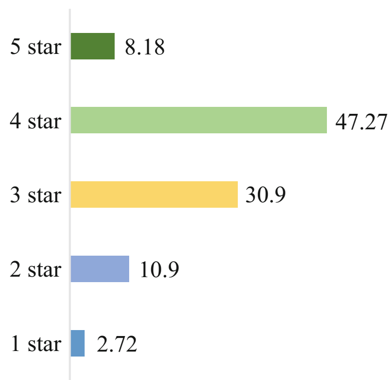
From the contextual inquiry, it is found that 45% of the students are satisfied with the lab resources such as raw materials, tools and devices. 17% of the students still expect more sophisticated resources such as better quality study materials and more spacious design lab. 47% of students have found the experiments to be intellectual, challenging, demanding and creative, whereas, 17% of them are in disagreement to this notion. From the enquiry it is noticed that these 17% students are not so fond of design and the design realization course failed to persuade their interest.

The overall skill development is excellent among 10% of the students and good among 44% of the students. 33% of the students are in the developing stage whereas skill development is perceived to be poor among 13% of the students. Skill development is dependent on the quality of teaching and one's interest to learn. Students from different disciplines, backgrounds, cultures are found to have different cognitions. The skill development also focuses on quality of interaction and competitive excellence.

Overall rating of the feedback given by the students has been calculated. As shown in Fig. 7 five star rating has been given by 8.18% of students whereas majority of the students have opted for 4 star rating. Only 2.72% of people have chosen single star rating. The majority of the students like this course because of its novelty and professionalism. In order to attain five star rating, it is suggested to introduce digital modelling rather than theoretical study. As per the survey, it is found that the experiments 1, 2 and 3 are more liked by the students as these experiments are based on concept selection and model-making with different materials such as plastic, metal sheet and clay. These experiments help them in realizing the products in more artistic way and enable them to exercise their creativity rather than performing complex theoretical analysis. Experiments 4, 5, 10 have received average ratings because they are a mixture of theoretical and practical exercises. Experiments 6, 7, 8 and 9 are mostly based on theoretical analysis and students are not clear about the concepts and hence, the rating is low (Fig. 8).

In order to validate these findings a comparative study is done with the course structure of IDC (Industrial Design Centre), School of Design, IIT Bombay [8]. It is

Fig. 7 Overall course rating feedback



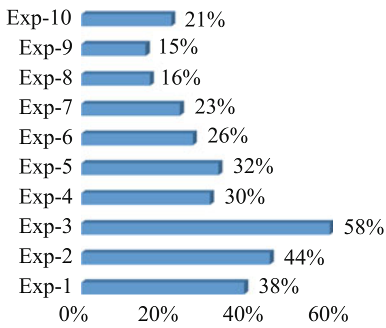


Fig. 8 Students' delight per experiment

found that at IIITDM Kancheepuram all the courses run parallel throughout the semester. Most of the theory courses have labs. But it's interesting to observe that although the theory and lab syllabi are designed to go with sync, if a mismatch happens the students face problems in understanding the concepts. In such cases the TAs (Teaching Assistants) and sometimes the faculties explain the theory briefly in the lab and the students continue to perform the experiments. On the other hand, in IDC courses run one after another. During the first hour of the day theory is taught followed by an assignment and during the second half the students are left free to do the assignments in their respective studios. The important point to notice here is that the theory and practice go side by side and with harmony.

Feedback has also been taken from professors and TAs to evaluate the course from an instructor's perspective. According to them, cons for the course are: students mostly tend to surf net for ideas rather than using their creative thinking, lack of knowledge among students about the motives and future scope of the course, they also seem to lack proper clarity about the objectives of the course, they don't understand and appreciate the advantages of the interdisciplinary design course. The pros are: the course is very different compared to all the routine courses offered. It's interactive, encourages inter-cultural mingling of ideas and improves artistic skills. The theory class in parallel to this lab course helps them to understand the design concepts well.

5 SWOT Analysis

SWOT analysis offers a clear picture for understanding a course or a program [9]. It provides many relevant information to the designer in one window. The SWOT outcome of the current framework is shown in Fig. 9.

As per the analysis, the major strengths of the course are found to be, its novelty in the mixture of interdisciplinary concepts, creative thinking aspects and professionalism whereas under-utilization of lab resources, lack of industrial design content in the syllabus and lack of concept testing before concept realization are noticed to be the weaknesses. There are opportunities to improve upon the current

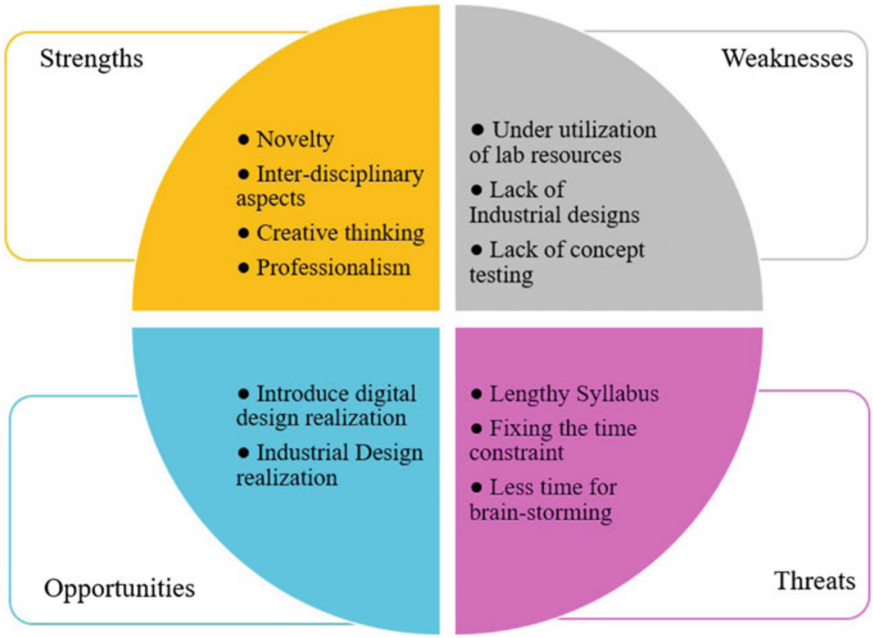


Fig. 9 SWOT analysis of the design realization course

curriculum in terms of introducing digital realization and industrial design realization. The threats are observed to be lengthy syllabus, less scope for brain storming and experiments are highly time constrained.

6 Conclusion and Future Work

IIITDM Kancheepuram believes in interdisciplinary course structure where the students can efficiently implement the design concepts in the field of Engineering, thus, providing a novelty to the Design Realization Course framework. Considering the qualitative and quantitative analysis done in this work, it can be concluded that the effectiveness of a course depends on various factors such as course structure, course organization, course delivery, pedagogical aspects and cognitive aspects of the learner. From the findings of the above work, it can be concluded that the course can be made more interactive and effective by providing flexibility in the time constraint. Theory and practical experiments should be in sync. It can be made more relevant and updated by providing industrial designs to the students as per the global demand. The future work is to invite similar evaluations from industrial experts and to share the improved frame work with the industries, academia and design related R&D establishments.

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Students' Feedback into Enriching Learning Experiences for Design of Smart Devices and Applications

Anmol Srivastava and Pradeep Yammiyavar

Abstract Innovative methods and technologies are required to improve students' learning experience in engineering laboratories. By considering the paradigm of ubiquitous computing to merge technology into everyday objects, it is possible to create intelligent tutoring systems in laboratories to achieve this goal. This paper presents a qualitative analysis of students' activities in an electronic engineering laboratory and maps them to the common types of errors they make in this setting. Some of these activities and errors causes hindrance for students which impedes their learning. It is posited that by minimizing these factors, the cognitive load can be reduced, thereby improving the learning experience. We present design guidelines for embedding intelligence into applications and smart devices that can be used in laboratories to reduce cognitive loads and improve students' learning experience. Data was collated using ethnographic methods involving observational studies, questionnaires, and semi-structures interviews.

Keywords Education · Ubiquitous computing · Embedded intelligence · Laboratory

1 Introduction

Practical laboratories in engineering institutes play an important role in providing hands-on learnings to students. However, current practices followed to make students learn concepts of experiments often proves insufficient in imparting the required learning experience. These practices are oriented more towards surface learning based approaches. i.e., involving students to reproduce information for assessment purpose only. Further, students performing practical experiments in

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laboratories are often faced with difficulties in procedures and experimental setup which often prevents them from making deeper inquiry into the experiment being conducted. Conducting pre-lab classes is often considered as an effective way to negate surface learning effect of the practical experiment. However, it does not prove to be a useful technique as very few students prefer to attend such classes or pay attention to them. Many classrooms employ a simulation based approach to help students visualize circuits and their working. Although it is effective means to understand it lacks hands-on capabilities. Observations also indicate that students often use smartphones and digital tablets in laboratories to search for required information using the Internet regarding practical experiment being performed by them. These devices also act as an enabler for mobile augmented reality (AR)—which can embed virtual information, such as 3D or 2D visualizations and videos onto real world scenarios. Thus it can act as a great medium to provide contextualized information and visualization to students in practical laboratories. However, in certain situations, where the experimental setup is complicated, students often need more hints and instructions regarding procedures or errors committed by them on a physical experimental setup than simple visualizations. In such cases, mobile AR applications and physical laboratory objects embedded with intelligence can help provide assistance to students. In physical experimental setups, sensors and microcontrollers can be used to embed intelligence. By doing so, such artifacts can sense various experimental parameters to be measured, given as input or observed by students and provide required instructions for students to follow. For this, it is important to understand—how intelligence needs to be embedded into laboratory artifacts? If embedded with intelligence, how can they act as an instructional medium that is able to assist students—similar to a human tutor? By considering Mark Weiser's vision [1] of ubiquitous computing where every day mundane objects are embedded with computational capabilities, this paper highlights the possibilities of introducing such artifacts—also referred to as smart learning objects (SLO), in engineering laboratories and presents design heuristics for weaving intelligence into them. Such objects can provide innovative and novel ways to enrich the learning experience of students in practical lab sessions.

2 Background and Related Work

Various research studies [2, 3, 4] conducted on students' learning in electronics laboratories indicate that students often get frustrated while experimenting due to procedural difficulties. These difficulties are also a major cause of distraction and frustration which inhibits students from making a deeper inquiry. Moreover, these labs are mostly instructor-dependents [2]. This often causes students to lose interest and motivation which pushes them towards boredom and simply getting over with the ritual of completing lab. Research [5, 6] in the field of education and cognitive psychology suggests developing instructions centered towards using knowledge as a problem-solving tool for students. This helps students move towards deeper inquiries about the relevant experiments. With the proliferation of new and emerging technologies, it is now possible to devise techniques and methods that can provide in situ student-centric instructions that are highly contextualized. As predicted by Dede [7], artifacts with semi-intelligence having capabilities to communicate wirelessly have already started taking shape and are finding increasing usage in educational sectors. These objects are mostly based on the idea of calm technology, as proposed by Weiser [1]. Studies [8, 8] present innovative approaches that integrate wireless sensor networks and context-aware technologies in laboratories to monitor students' learning skills and guide inexperienced researchers in operating equipment in laboratories. Hwang et al. [9] also defines the tutoring strategy based on IF-THEN rules to guide learners in such a system. Further examples of using emerging technologies in like AR in laboratories can be seen from published research [10, 11]. A study [12] proposes direct interaction with PCB using a probe to obtain just-in-time information regarding the schematics. Such a system shows potential for adoption as an instructional tool in the electronics lab. The literature survey reveals that very few studies have been conducted in terms of enriching learning experience of students in electronics engineering labs using emerging technologies such as smart physical objects or augmented reality. Further, these studies also lack the guidelines on how to and what type of intelligence needs to be embedded in such systems. Such guidelines can be useful for education technology designers to develop learning aids using new technologies for students. To explore how these guidelines could be developed, design methods as practiced in usability engineering were adopted. The following section describes these.

3 Methodology

The study employed User Centered Design approach as practiced in Human-Computer Interaction (HCI). Various usability methods like think-aloud sessions and task-flow analysis were used to come up with design guidelines for embedding intelligence into SLO and AR applications. These have been discussed as follows.

3.1 Interviews

20 undergraduate students and four-course instructors of electronics engineering branch were interviewed. The interviews were transcribed and analyzed using content analysis.

3.2 Questionnaire

By the results obtained from interviews, a questionnaire was sent to first year undergraduate students enrolled in Basic Electronics Laboratory course (EE102) via e-mail. Out of 76 responses, 65 usable questionnaires were received. Ages ranged from 17 to 20 years, with an average age of 18 years. The questionnaire consisted of 20 items. The participants were asked to rate their confidence level on the ability to understand various electronic components, operating test equipment, assembling circuit and troubleshooting on a 10-point Likert scale (1 = Low, 10 = High). Table 1 presents a section of the questionnaire. The reliability analysis of this questionnaire gave a Cronbach's alpha score of 0.913. In addition to these 15 items, five items asked participants to rate, on a 5-point Likert scale, how they used the internet for collecting information regarding given experiment and distraction it caused. Further, as Cathode Ray Oscilloscope (CRO) was reported to be the most difficult test instrument to operate in the lab, subjective measurement of the cognitive load experienced by students (N = 23) for operating CRO was taken using NASA TLX questionnaire [13] which was given immediately after their lab session, refer Fig. 1.

Overall mean weighted workload (MWWL) experienced by students for operating CRO alone is 50.71. Apart from this, an open-ended questionnaire was given to students asking them to describe anything they mainly found good or frustrating while performing experiments. We also gave the questionnaire to lab assistants (N = 3) and course instructors (N = 2) asking problems faced by them in labs and to highlight areas they felt were difficult for students.

Table 1 A section of questionnaire showing descriptive statistics of students' ability. N = 65

Items	Mean	Std. dev
Ability to understand and operate features of CRO at first attempt	7.88	1.980
Ability to operate the features on CRO when it behaves unpredictably	6.80	2.244
Ability to measure and interpret waveform of CRO	8.37	1.645
Ability to set correct amplitude and frequency on function generator	8.74	1.814

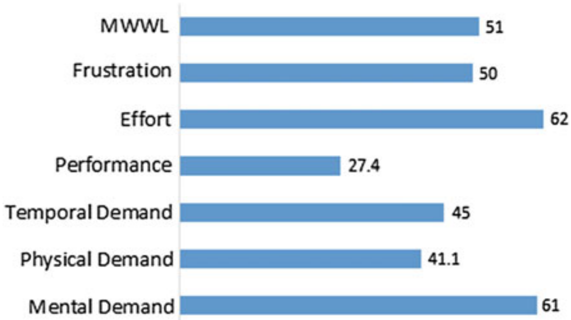

Fig. 1 Graph depicting mean sources of workload experienced by students, (N = 23), for operating CRO alone. 0 = Low, 100 = High

3.3 Interaction Analysis

Video recordings made of live laboratory sessions and think aloud sessions were analyzed using interaction analysis process as described in the literature [14]. Through these analyses, the laboratory activity, as performed by students, were broadly broken down into four steps (see Fig. 2)—(a) Referencing; (b) Assembling; (c) Operating test equipment (OTE); (d) Reporting. Figure 4 depicts a basic block diagram of these actives and inter-relation between them.

4 Findings and Analysis

Figure 3 depicts the difficulties faced by students based on the total responses obtained from open-ended questionnaire and interviews (N = 46). The analysis of the questionnaire revealed that although students rated high confidence regarding

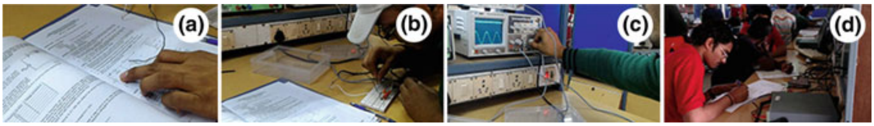

Fig. 2 An atypical interaction analysis of think-aloud sessions and live laboratory sessions. **a** Referencing from lab manual. **b** Assembling the circuit by continuously referring to lab manual. **c** Operating test instrument to provide input to the circuit and measure output. **d** Reporting the findings and observations

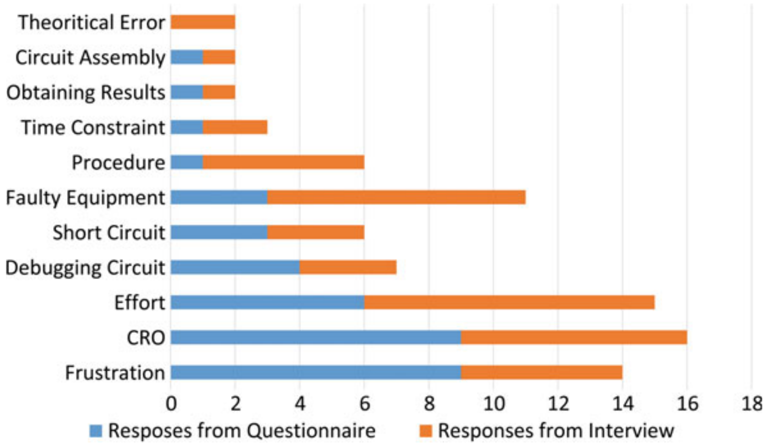

Fig. 3 Difficulties experienced by students in electronics laboratory. The graph was obtained after content analysis of interviews and open-ended questionnaire for N = 46 students

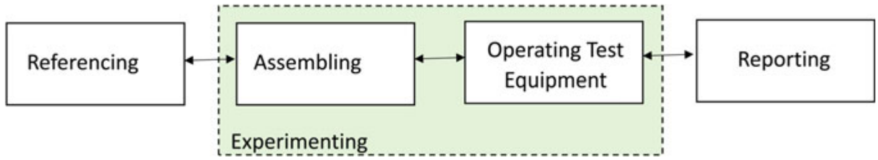

Fig. 4 Block diagram of students' activity in a practical lab session. Assembling and operating test equipment form a major part of this process needed to build and test a hypothesis

their ability to troubleshoot and operate various test equipment, the interviews yielded opposite results. This indicates that students often come unprepared in laboratories or have a little understanding regarding the working of such instruments. It was also found that searching for information on the internet in labs was time-consuming and distracting for students. Further, the amount of effort and frustration experienced by students to debug large circuits and operate test instruments often inhibits deeper inquiry into the crux of experiment and underlying theory. Referring to Fig. 1, it is evident that merely operating a CRO—which is only a part of whole activity while experimenting requires high effort and causes frustration.

From the questionnaire given to course instructors and their interviews, it was found that many students get confused while using breadboards and often do not follow the practice of using a series column as a ground (GND) or voltage supply. It was also reported that loose connections and unsystematic wiring of circuits by students are the primary cause of errors. The instructors also highlighted that students do not systematically debug circuits and give up in between while debugging. They also emphasized that students' often come unprepared for lab classes, which is one of the main reason for their lack of understanding regarding experiments. Operating CRO was also reported as a problem faced by the student.

5 Design Guidelines for Embedding Intelligence

5.1 Mapping Errors and Instructions to Experimental Task-Flow

In a lab environment, students need to interact with an experimental setup to perform the practical. Through interaction analysis, laboratory activity of students for conducting experiment has been broadly categorized in four steps (refer Fig. 4).

It is during assembling and operating test equipment that significant errors or mistakes are made by students which cause increased effort, mental demand, and frustration. As observed from videos, interviews, think-aloud sessions and open-ended questionnaire, such errors can be classified into four categories. These are—(i) Physical errors, (ii) Perceptual errors, (iii) Theoretical errors and

Table 2 Types of errors made by students while doing practical experiments mapped to the activity

Type of error	Description	Activity
Physical	Break in connection not visible to human eye Loose connections Wrong arrangements of components	Assembling, OTE
Perceptual (visual perception)	Wrong connection Use of faulty electronic component	Referencing, assembling, OTE, reporting
Theoretical	Wrong understanding regarding electronic component, test equipment or experiment	Referencing, assembling reporting
Technical	Faulty lab equipment and objects	Assembling, OTE

(iv) Technical errors. Physical errors and perceptual errors can partly be categorized under the interactional errors, i.e., errors that happen while interacting with the experimental setup. While not all physical errors contribute to mistakes made by students (e.g. loose connections), wrong connections or placement of components does. Perceptual errors are mostly visual in nature. These can occur during any of the four stages of experimental activity. However, while conducting a practical experiment, they happen when students visually perceive connections or components wrongly. Table 2 describes these errors mapped to students' activity in a practical electronics lab.

We posit that if a system can guide students through this process while minimizing the number of trial and error efforts required in debugging circuits or operating test instruments, an effective learning experience can be created for students. Such a system would then be capable of reducing the amount of frustration and cognitive load of students. Studies [5, 6] from cognitive science show that for knowledge assimilation and schema formation to take place, cognitive load experienced by students should be minimal. Hence, developing physically intelligent agents capable of embodying highly structured information and instructions can help students learn effectively in a lab. The basis of this statement sprouts from the work on AR [15], tangible interaction [16] and human ideation [17] that highlight the importance of physicality, natural affordance and interface of objects. Further, as reported in the interviews, a major concern for course instructors in these labs is to be able to relate theoretical aspects of the experiment to practical, real-life applications. For this is it necessary to provide highly situated and contextualized instructions for students which can help them relate to such concepts. Hence there is a need to generate suitable instructional algorithms that embody tacit knowledge of instructors which is highly structured in nature. For doing so, Task flow diagrams (TFD) were created from think-aloud sessions and observational studies for experiments reported to be difficult for students. These TFDs highlighted various instructions that should be generated when certain type of error is encountered and that invoked inquiry-based learning in students during various steps of the experiment. The instructions were captured from interviews of lab instructors. Figure 5 depicts a segment of one such task flow diagram generated for an experiment.

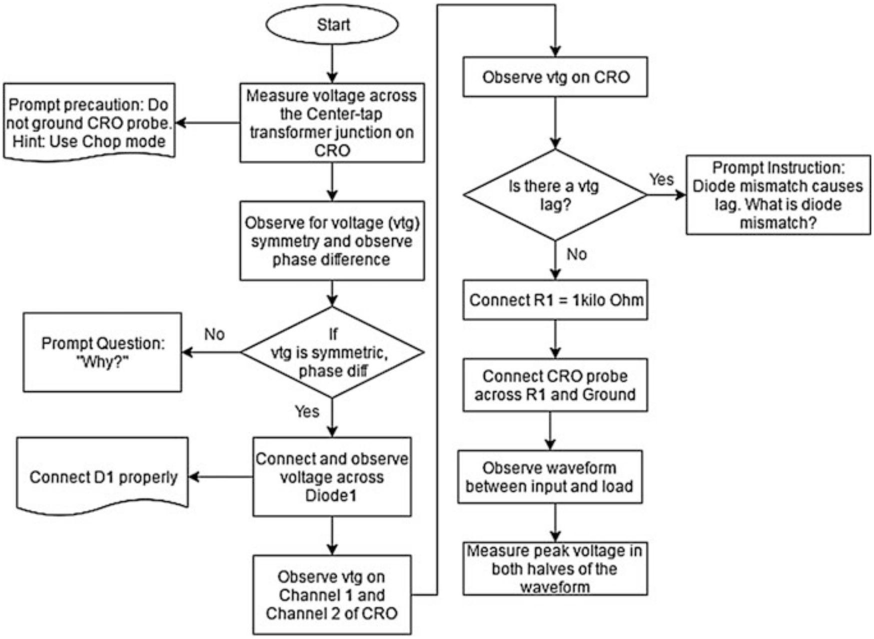

Fig. 5 A section of task flow diagrams generated for full-wave rectifier experiment

5.2 *Defining Intelligent Systems*

The complete experimental setup usually consists of various objects and equipment in labs. Students while working with this setup interact with various objects in this scenario and also distribute a part of their intelligence into those tools [18]. Mapping errors to the task-flows help in cataloging the types of interactions that are likely to happen between the experimental setup and students. By identifying objects that are used most by students and have a high likelihood of producing interactional errors can be chosen to be embedded with computational capabilities to sense such mistakes. Doing so creates a tangible user interface (TUI) that acts as an input mechanism for error and task sensing. From such system, further developments can be made to define what types of instructions are most suitable for students depending upon the state sensed by TUI. To effectively convey these instructions to students, various types of output modalities can be defined. These have to be chosen such that students get the most out of their learning experience. Hence, as we move towards increasing the experiential learning value, we are also tending towards increasing the Degrees of Intelligence (DOI) to be embedding into our tutoring system. Figure 6 represents a block diagram of such a system and partly conveys how intelligence is being embedded into the objects which when

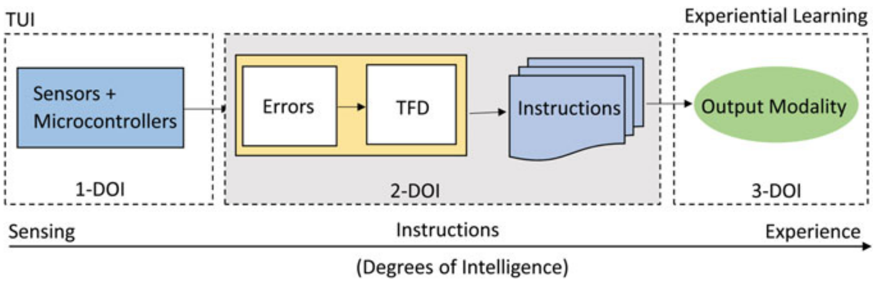

Fig. 6 Block diagram representing increasing degrees of intelligence embedded into the learning system

used in combination of with other equipment and instruments in a lab, from an intelligent tutoring system for students in the lab. The sensing layer contributes towards a first degree of intelligence (1-DOI) and is mainly responsible for sensing and computing functions. Developing adequate instructions and learning content corresponding to task-flows and errors is the second degree of intelligence (2-DOI). Designing rich learning experience and interactions with the system is a third degree of intelligence (3-DOI).

It is important to note that such systems have distributed intelligence, i.e., an object embedded with certain computational capability alone cannot act like a complete medium for learning. It is through multiple modes that it interacts and provides required instructions and experience to students. This framework requires further exploration and development.

6 Conclusion

This paper presents guidelines for embedding intelligence into applications and learning objects used in electronic laboratories. Such objects can further be used in conjunction with emerging technologies like AR to provide active visualization to students. Although limited in their functionalities, these objects can provide a good basis for providing new means to generate contextualized instructions and visualizations. The idea is to sense experimental parameters and send it to an instructional decision-making module, which generates the right content at the right time. This can help students focus their attentions on main problems and concept of the experiment rather than struggling with trivial issues. Designing such modules employ practices of HCI coupled with those of artificial intelligence. Altogether, such tutoring systems can act almost similar to that of a human instructor by embodying their tacit knowledge which can be distributed over various sub-systems of experimental setups. Thus new means of learning can be devised for augmenting learning of students in electronics laboratories.

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Erratum to: Connotations of Ecodesign: A Commentary on the State of Discourse

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Erratum to:
Chapter "Connotations of Ecodesign: A Commentary on the State of Discourse" in: A. Chakrabarti and D. Chakrabarti (eds.), *Research into Design for Communities, Volume 2*, Smart Innovation, Systems and Technologies 66, DOI 10.1007/978-981-10-3521-0_35

In the original version of the book, belated corrections in Table 1 of Chapter "Connotations of Ecodesign: A Commentary on the State of Discourse" have to be incorporated. The erratum chapter and the book have been updated with the changes.

The updated online version of this chapter can be found at
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