

# **Development of a Morphological Approach in Sustainable Product Designing**

A thesis submitted in partial fulfilment of the requirements for the degree of

**Doctor of Philosophy**

by

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## DECLARATION

I hereby declare that the work contained in this thesis entitled “**Development of a Morphological Approach in Sustainable Product Designing**” is my own work done under the supervision of **Professor Pradeep G. Yammiyavar**, at the Department of Design, Indian Institute of Technology Guwahati (IITG), Assam. I hereby declare that to the best of my knowledge, it contains no materials previously published or written by another person, or substantial proportion of material which have been accepted for the award of any other degree or diploma at IITG or any other educational institute, except where due acknowledgement is made in this thesis. Any contribution made to the research made by others, with whom I have worked at IITG or elsewhere, is explicitly acknowledged in the thesis. I also hereby declare that the intellectual content of this thesis is the product of my work, and as per general norms of reporting research findings, due acknowledgements have been made wherever the research findings of other researchers have been cited in this thesis.

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## CERTIFICATE

This is to certify that the work contained in this thesis entitled “**Development of a Morphological Approach in Sustainable Product Designing**” submitted by Mr. Vikash Kumar to the Indian Institute of Technology Guwahati, Assam (India) for the award of the degree of Doctor of Philosophy has been carried out under my supervision. This work has not been submitted elsewhere for the award of any other degree or diploma.

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To my parents

Late Dr Birendra Kumar Singh  
Ms. Nilam Singh

and my gurus

Professor Pradeep G. Yammiyavar  
Ms. Suchitra Gauri

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## Abstract

The presented thesis is an attempt to develop a morphological approach in sustainable product designing. Design being one of the fundamental activities of human beings has contributed significantly towards the escalation of mass production and mass consumption. This growth has resulted in the existing consumerism based society and socio-economic development trends, which in recent years was found to be unsustainable. Therefore, there is an urgent need to rethink and realign our activities in a sustainable direction. Design as an activity and field of study has a tremendous potential towards contributing to sustainable development. This potential proliferate the consensus of integrating sustainability philosophy with design practice.

In recent years, it has acquired the status of the cornerstone in design research. Many researchers argue, that in today's context, designing for sustainability is no longer optional, and should be treated as an integral part of the design process. However, literature evidences that this has not yet happened in practice. In general, sustainability parameters are either considered optional or as an added set of constraints limiting the design space. Moreover, the traditional morphologies of design process available in the popular literature were found to be inadequate for sustainable designing.

This research builds on this recently evolved consensus of many design researchers and intends to develop a morphological approach in sustainable product designing. The thesis identified the 'creative phase' of design process ideally suited for sustainability integration. This is due to its various merits, like complexity handling capacity, the flexibility of decision making, and altering it at low cost, etc.

This thesis identified, and attempted to address three research gaps in sustainable design, and tailored its findings to propose the morphological approach in sustainable product designing. It employed extensive literature analysis and empirical study with creative designers for the purpose.

The first research gap addressed in this thesis focuses on developing a comprehensive framework for sustainable design. Frameworks are the logical structures that make any concept (or philosophy) understandable, especially to novice and non-experts. The philosophy of sustainable design in literature was found to be diverse and interpretative in nature. Moreover, available frameworks and conceptual models representing the philosophy were found to be inadequate for creative designers.

This research derived a comprehensive framework for sustainable design, addressing the first research gap. This framework proposed ten directions of sustainability, applicable at product, lifecycle, and system levels. Four kind of inter and intra-dimensional relationships were identified among these directions and were presented as interaction matrix. The framework (with 10 sustainability directions) was expected to support creative designers in exploring sustainability issues at analysis phase of design. The interaction matrix was expected to reflect on the effect of design decisions on other directions of sustainability at synthesis phase.

The second research gap addressed in this thesis was directed towards understanding the mental models and problem-solving approaches in sustainable design, as practiced by creative designers. Mental models are internal symbol or representation of external reality, hypothesized to play a major role in cognition, reasoning and decision-making. It is imperative that a flawed or an incomplete mental model of sustainable design will reflect in the problem-solving approaches of creative designers. Problem-solving approaches under normal circumstances has been extensively studied empirically and reported in the literature; however designing with sustainability consideration was not adequately addressed in the literature. Such study was anticipated to reveal how creative designers interpret, and use sustainability philosophy in practice. It was also expected to reveal in the nature of support tool required for sustainable designing

This thesis reported an empirical study conducted for exploring the mental models and problem-solving approaches of creative designers. The study revealed that despite the broadening of scope and dimension of sustainable design, existing mental models of novice creative designers are still rooted in the environmental-conscious philosophies of design. It also indicated that novice designers tend to follow traditional design morphology but, made additional changes to accommodate sustainability consideration. This behaviour reflects the limitations of traditional design morphologies in the context of sustainable designing and points out the need of improved morphology.

The third research gap addressed in this thesis focuses on developing morphology for incorporating sustainability issues into the creative design phase. Traditionally designers are trained for designing products that satisfy human needs and aspiration. However, in literature there is a lack of an operational method for incorporating sustainability issues into the creative design phase.

This thesis tailored the findings of previous two research gaps and proposed a model of morphology for sustainable designing. This morphology was expected to provide creative designers with an operational method of approaching sustainability. It was validated through a dry run test using mobile phones as a sample product. The test pointed out new directions for improving the sustainability of products. These directions were not found to be adequately addressed in the literature, indicating the success of the proposed morphology.



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## Chapter 1

# An Introduction to Creative Design and Sustainability

This chapter introduces the research work reported in this thesis. It builds on the recently evolved consensus of integrating sustainability philosophy with the practice of design and argues that the creative phase of design is very critical in incorporating sustainability issues. Moreover, building a right perception and understanding of sustainability during design training is very crucial for creative designers. It can be a promising entry point for integration of sustainability thinking within design practice. This research posits that one of the potential ways of doing so is the morphological approach for sustainable product designing. The chapter starts with a brief introduction to the area of research and its background, covered in section 1.1 and 1.2. Section 1.3 elaborates on the research gaps and section 1.4 highlights on the research questions, objectives and working posits that are addressed in this thesis. Section 1.5 discusses the methodological framework of how the research was conducted. A brief discussion on the positioning of this research with respect to the existing body of knowledge is presented in section 1.6. The chapter concludes with section 1.7 which presents an overall layout of the thesis, giving an outline of the chapters in which the thesis is structured.

## 1.1. Introduction

Design is one of the most fundamental activities of human beings. Its primary objective is to conceive and create an environment that satisfy human needs and wants (Cross, 2006; Simon, 1996). With the advent of the industrial society during the 1750s, design was used as one of the tools for escalation of mass production and mass consumption of products and services. This trend contributed to the existing consumerism based society and socio-economic development trend. However, researches in the recent past indicate that this trend of development cannot be sustained for long. The existing practices of production and consumption are heading towards an unsustainable future (Vanasupa et al., 2010; WWF, 2012). This is due to the fact that the Earth's resources are limited, beyond which she cannot sustain human life (Vanasupa et al., 2010; Wackernagel et al., 2002; WWF, 2012). Therefore, there is an urgent need to rethink and realign our activities of production and consumption, such that it stays within sustainable limits (Vanasupa et al., 2010). This realisation has propagated the concern over achieving sustainability as one of the greatest goals of humanity to survive on Earth. In recent years vigorous efforts have been undertaken in this direction by various disciplines and field of study, including the creative discipline of design as applied to products and environments.

Design being one of the most important activities behind the propagation of existing consumerism based society is also attempting to realign its activities towards contributing to sustainability. In the past various environmental conscious philosophies like 'green design', 'eco-design' etc. were developed to incorporate sustainability thinking in design practice (Knight, 2009). The most recent to this, is the philosophy of 'Sustainable Design', and is the focus of this thesis. This philosophy in recent years has become one of the cornerstone of design research, with a significant amount of literature published towards incorporating it into the day to day practice of designing (Bovea & Pérez-Belis, 2012; Gagnon, Leduc, & Savard, 2012; Kengpol & Boonkanit, 2011; T Sakao, 2007; Vinodh & Rathod, 2010; S. A. Waage, 2007; Xing, Abhary, & Luong, 2003). The presented research builds on this recently evolved consensus of many design researchers and explores the morphological development approach towards sustainable product designing.

In recent years, design literature have witnessed the development of many new methods, tools, principles etc. to support the incorporation of sustainability thinking within the process of designing (Bovea & Pérez-Belis, 2012; Lewis & Gertsakis, 2001).

However, there are many researchers who argue that in general, sustainability comes into picture only in the later stages of the design process. There are limited researches towards understanding and incorporating the concept in the initial phase of designing (Lin, Chiu, & Okudan, 2009; Sherwin, 2004).

The initial phase of design (also referred as conceptual design or creative design) is often considered the heart of the design process (Chen, Liu, & Xie, 2012; Kolodner & Wills, 1996). It is the phase where high-level designs (concepts) are conceived, and is considered responsible for up to 85% decisions affecting the lifecycle cost of any product (Macmillan, Steele, Austin, Kirby, & Spence, 2001; Zuo & Director, 2000). These decisions are also likely to affect the sustainability of the products. Therefore, there are researchers who believe that this stage can play a very significant role in incorporating sustainability in design (Lin et al., 2009; Sherwin, 2004). This role, however, has not received as much attention from design researchers as it deserves, especially at practice levels (Sherwin, 2004). The presented research is an attempt to explore this role in establishing sustainability, and how best it can be integrated with the practice of creative design.

## 1.2. Research Background

The background of this research is rooted in three broad areas of study, namely design science, sustainability science and the interdisciplinary field of sustainable design. This section starts with an examination of sustainability as a philosophy and its evolution in design discipline (sustainable design). It then examines the practice of creative design within the morphology of design process, discussed in section 1.2.3 (page 6). The section concludes indicating the potential role that creative design can play in incorporating sustainability into the design process.

### 1.2.1. The Philosophy of Sustainability

The philosophy of 'Sustainability' started evolving with the realisation that the Earth's carrying capacity is limited beyond which she cannot sustain life. The existing trend of consumerism based development is consuming resources beyond the planet's carrying capacity. As a result, there is an increasing gap between nature's supply and human demand that is leading us towards an unsustainable future (WWF, 2010). Figure 1.1 illustrates the extrapolation of this gap expressed in terms of ecological footprint. Clearly,

this trend of development is heading towards an unsustainable future. However, this situation can be avoided through sustainable utilisation of resources and by maintaining a certain status quo in nature (IUCN, 1980). The broader aim of sustainability is thus to reduce the resource consumption rate within the earth's sustainable limits and maintain it for a very long time.

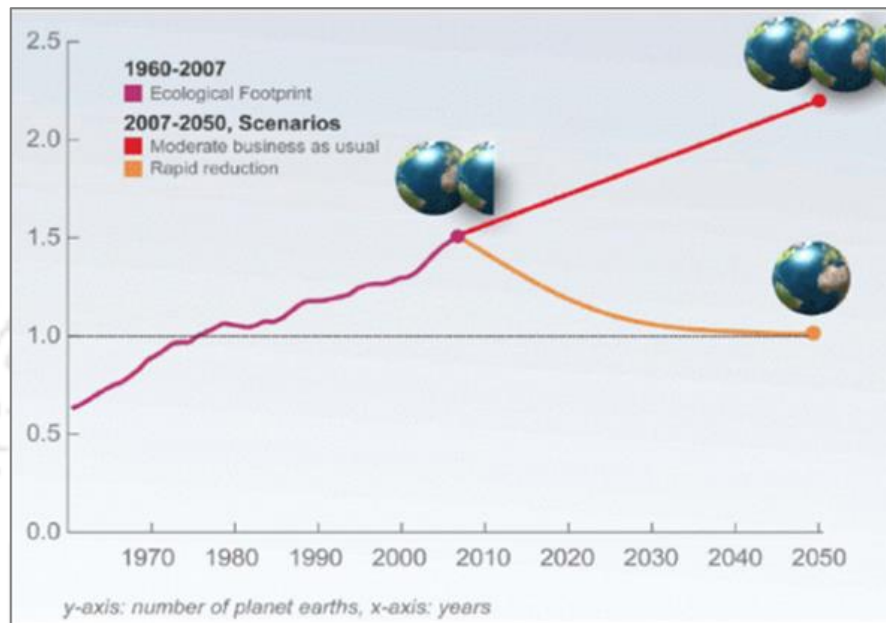


Figure 1-1: Trend of human's ecological footprint

Source: <http://www.footprintnetwork.org>

In order to achieve sustainability, Brundtland Commission proposed the philosophy of 'Sustainable Development' in 1987, which was defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland, 1987). This philosophy encompasses the three broad dimensions of sustainability namely environment (planet), society (people) and economy (profit) (Elkington, 1994). The generic nature of its definition often attracted criticism in literature about being ambiguous and open to interpretations (Holden & Linnerud, 2007; N. Middleton, O'Keefe, & Moyo, 1993; Wackernagel & Rees, 1996). However, there was a consensus among researchers towards incorporating it into the various activities of governments, organisations, industries, communities and society as a whole (Gagnon et al., 2012). Many disciplines and fields of study have also absorbed this philosophy and are attempting to incorporate it into their practices. Design as a discipline has also absorbed this philosophy popularly recognised as 'sustainable design' (or 'design for sustainability') and is elaborated in the following section.

### 1.2.2. Sustainable Design and its Evolution

Sustainable design as a philosophy is considered to have evolved as a result of incorporation of sustainable development in design discipline. However, in design literature it is also seen as a philosophy that evolved from the earlier environmental conscious philosophies like green design and eco-design (Knight, 2009). Both ways it finds its root in environmentalism and environmental worldviews which defines the human relationship with their environment (Dusch, Crilly, & Moultrie, 2010). Figure 1-2 illustrates this evolution (discussed elaborately in Section 2.3, page 31).

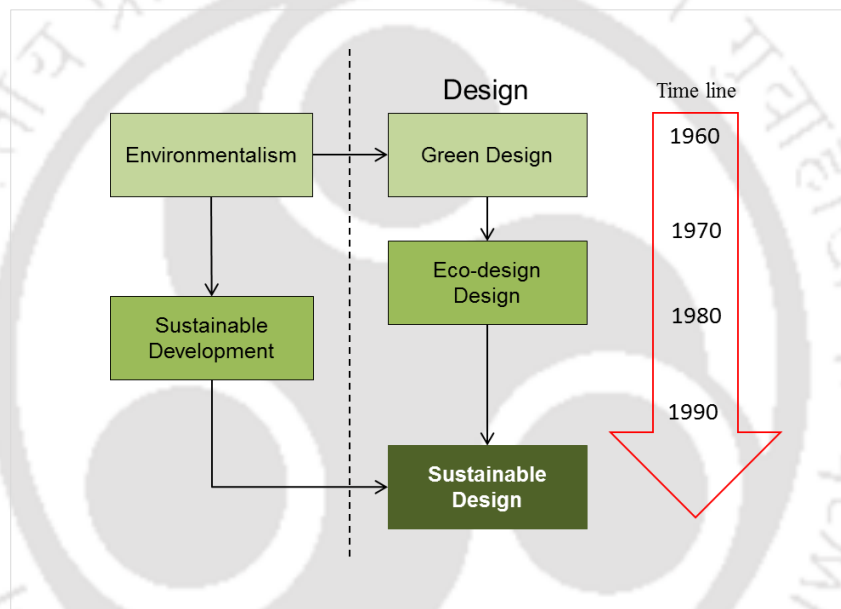


Figure 1-2: Evolution of Sustainable Design

Source: Author-generated based on consolidated findings from literature

The philosophy of green design was a product-centric approach towards reducing environmental impacts through waste prevention, toxicity reduction, better material management, remanufacturing, energy recovery, life extension, etc. (Knight, 2009). Eco-design was also concerned with environmental efficiency of products, but its approach widened to life-cycle level (Knight, 2009). These two concepts further widened its scope from product to lifecycle to system level in the philosophy of sustainable design. It was also influenced by the philosophy of sustainable development that led to the incorporation of the socio-economic dimension along with environmental concerns (Walker, 2002).

Sustainable Design as a philosophy is still considered evolving, as its understating in literature is often contested. One of the prominent reasons for this is its

close correspondence with sustainable development philosophy which itself is considered ambiguous and open to interpretation (Holden & Linnerud, 2007; N. Middleton et al., 1993; Wackernagel & Rees, 1996). Consequently, the literature reflects varying definitions and understanding of sustainable design that often creates confusion in practice (elaborated in Section 2.4, page 34). Despite this ambiguity, the concept is becoming increasingly important for designers. Lindley (as cited in (Kjøllesdal, Asheim, & Boks, 2012)) argues that in today's context designers should not have a choice between becoming a "product designer" or a "sustainable product designer". In recent years, several researchers have advocated that it should be considered as an integral part of the design process (Boks & Diehl, 2006; Kjøllesdal et al., 2012).

The most important phase of the design process is creative phase, and many researchers believe that this phase is ideal for incorporating sustainability issues (Lin et al., 2009; Sherwin, 2004). The following section elaborates on the morphology of designing, highlighting on creative design as an important stage from a sustainability perspective.

### 1.2.3. Creative Design and its Morphology

The process of designing consists of a chain of activities, which starts with an abstract problem and through the iterative process of analysis, synthesis and evaluation results in a concrete solution (Blessing, 1994). This sequence of activities is often expressed in the form of design morphology. It can be understood as a standard method, or a recipe that captures the essence of designing in the form of a sequence of activities. In practice it is concerned with "how" and "when" things should happen, and in what desired order. The main objective of design morphology is to devise a concrete course of action, which can guide designers (especially novice ones) towards successful design solutions (Jones, 1984; Pahl & Beitz, 1999).

Howard, Culley and Dekoninck (2008) made a comparative analysis of more than 23 design morphologies and found out that there is a general agreement in activities to be carried out. The most common activities were found to be 'analysis of task', 'conceptual design', 'embodiment design' and 'detailed design' (Howard, Culley, & Dekoninck, 2008). Apart from these four activities 'establishing the need' (preceding 'analysis of task') and 'implementation phase' (followed by 'detailed design') were additional activities in few cases (Howard et al., 2008). Figure 1.3 illustrates an example of design

morphology proposed by French (1999) highlighting the most common activities found across different morphologies.

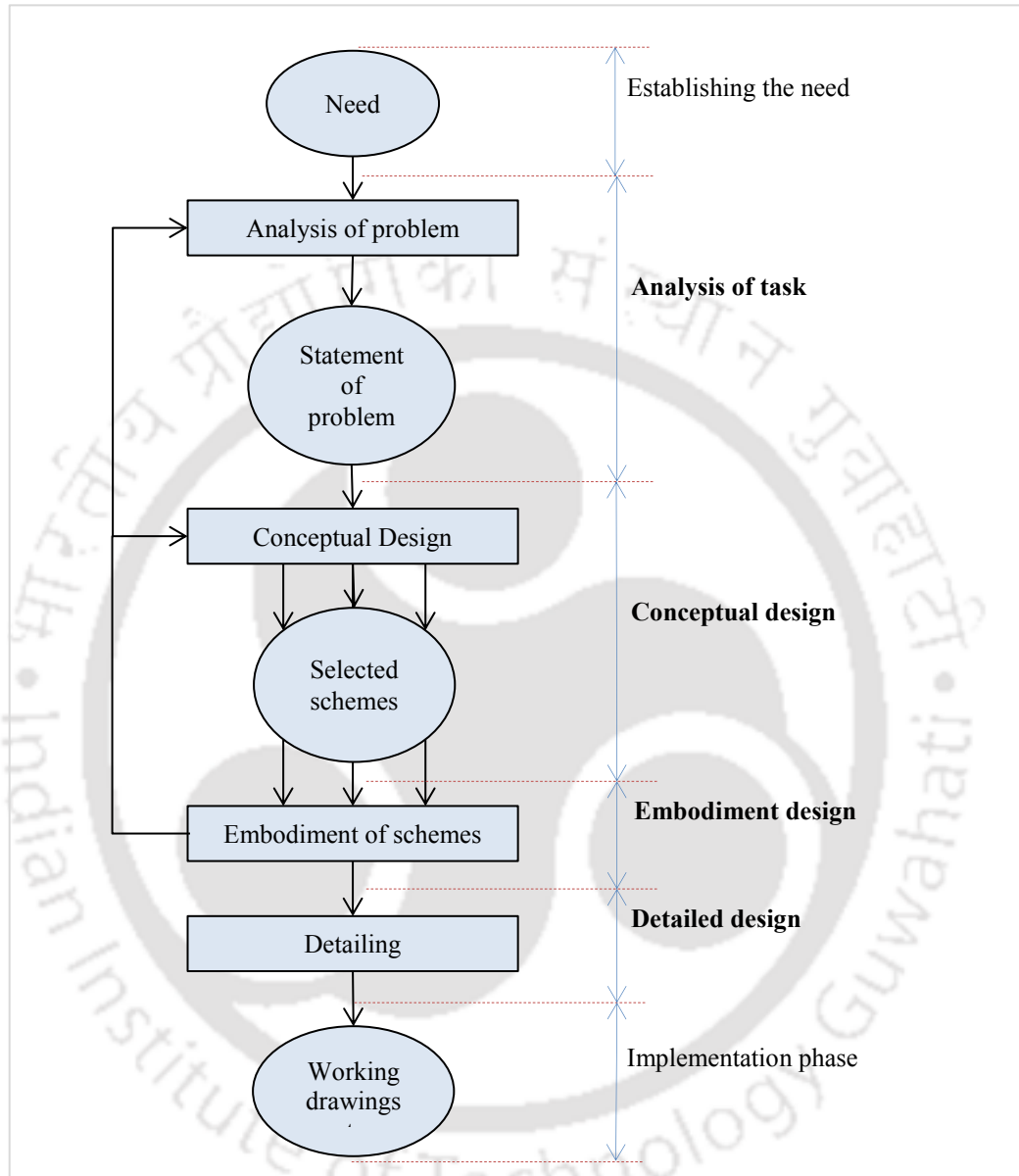
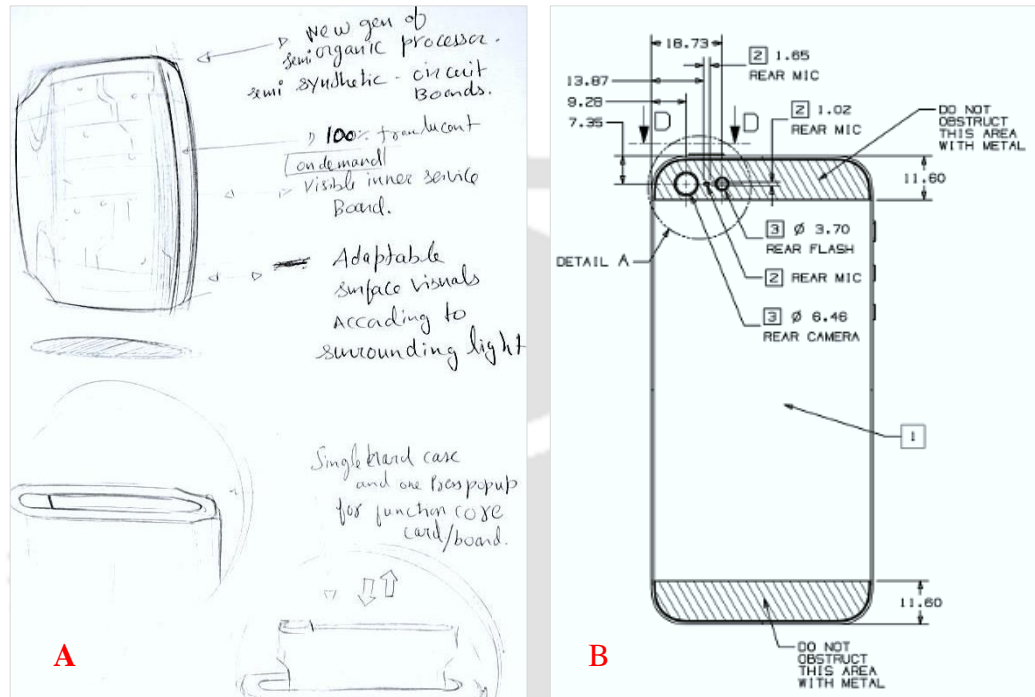


Figure 1-3: An example of design morphology against common activities across morphologies

Source: Consolidation from French (1999) and (Howard et al., 2008)

Within the process of design, the conceptual design and embodiment design together is found to be in close correspondence with creative processes (Howard et al., 2008). That is why this part of design morphology is often recognised as the creative phase of design. The phase consists an iterative process of problem definition, issue isolation and concept formation (Zuo & Director, 2000). Designers in this phase generally start with a very poorly defined problem (often referred as wicked problems), and as they

proceed, two kinds of problems are encountered namely understanding the problem, and finding the solution to that problem. Most often these two activities happen simultaneously/hand-in-hand, and it is difficult to segregate both the activities. The process continues depending upon the resources and time available, and the designer stops with the most appropriate solution to the problem.



**Figure 1-4:** Illustration showing the difference in work of (A) creative designer and (B) engineering designer

Source: (A) Respondent-generated (while empirical study reported in chapter 5);

(B) <http://www.gottabemobile.com/2013/09/05/iphone-5-cases-will-fit-iphone-5s-according-to-case-makers/>

It should be noted that the term ‘creative designer’ is being used here in this thesis to distinguish their activities from that of an ‘engineering designer’ who is also involved in designing products. A creative designer, in general, is associated with designing products with ‘user’ as the centre of the decision making (user centred design). Their parameters are primarily focused on human factors, usability, and aesthetics (user experience) (Cross, 2008; Eder & Hosnedl, 2010). Engineering designer, on the other hand, is focused on solving the engineering problem. Their parameters are primarily focused on functional efficiency, manufacturing, assembly, distribution, etc. (Cross, 2008; Eder & Hosnedl, 2010). The end product of a creative design process (in general) is a conceptual sketch or rendering as shown in Figure 1.4 (A), whereas the deliverable of an engineering design is manufacturing drawing in CAD/CAM /CIM as shown in Figure 1.4 (B).

Apart from these differences, Table 1.1 derives the other major differences from the works of Cross, 2008; Wölfel, 2008; Eder & Hosnedl, 2010. For clarity, creative design in this thesis is identifiable with ICSID's defined profession of design that has creativity as its central theme. However, it does not exclude engineering designers who employ the creative design morphology.

**Table 1-1: Difference between creative design and engineering design**  
Source: Derived from (Cross, 2008; Wölfel, 2008; Eder & Hosnedl, 2010)

| Engineering Design   | Creative Design   |
|--|---|
| Engineering design problems are either structured or can be very easily structured.                      | Creative design problems are ill-structured and difficult to structure. That is why the first step of a creative design process is to redefine the problem. |
| Engineering design is aimed at a single optimum solution with precision as the most important parameter. | The creative design aims at multiple solutions where simplicity and appropriateness are the key parameters.   |
| Engineering design solutions fits within the parameter boundary and innovates within reality.            | Creative Design stretches the boundary beyond parameters and creates a new reality to innovate.   |
| Engineering Design is analysis dominated, and vertical thinking is employed                              | Creative Design is synthesis dominated and employs lateral as well as vertical thinking.  |
| The problem solver in engineering design is neutral and do not bias the result.                          | Problem solver becomes an additional variable biasing the result  |

Creative Design phase is the most crucial step of designing, as the decisions taken at this stage is responsible for up to 85% of the life cycle cost of products (Cross, 2008; S. Waage, Geiser, & Irwin, 2005; Zuo & Director, 2000). These decisions have a significant effect on other aspects of the products' life cycle. This stage provides a lot of freedom for making design modification, and the cost of modification is very low. These attributes makes this phase of designing very critical in solving complex technical problems (Carayannis & Coleman, 2005; Naes & Nyvold, 2004; Taylor, 2009). Figure 1.5 illustrates the variations in design modification cost, product knowledge (details of the product) and freedom of design modification on a timescale (adapted from Lindahl (2005)).

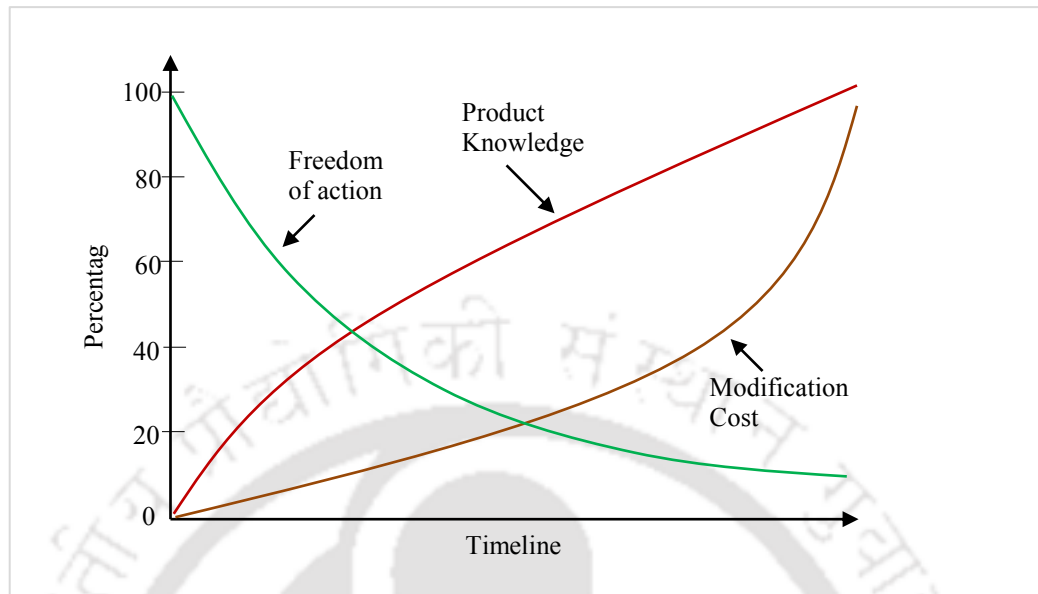


Figure 1-5: Freedom of action, product knowledge and modification cost on timescale

Source: Adapted from Lindahl (2005)

These characteristics of creative design phase made many researchers believe that it can play a very significant role in incorporating sustainability philosophy within the practice of designing. This thesis also supports their views and presents the following section in support of their belief.

#### 1.2.4. Creative Design and Sustainability

Integrating the philosophy of sustainability with the process of designing (design morphology) have been reported in literature as one of the most promising method of sustainable design (Gagnon et al., 2012; T Sakao, 2007; Xing et al., 2003). However, there are many researchers who argue that in practice sustainability comes into picture only in the later stages of the design process (Lin et al., 2009; Sherwin, 2004). Sherwin (2004) while sharing his professional experience as a designer points out that sustainability issues are considered external to the creative design phase (Sherwin, 2004).

As pointed out in previous section creative design phase is the heart of design process from the decision-making point of view, as it has a significant impact on the whole lifecycle of any product. According to many researchers (Cross, 2008; S. Waage et al., 2005; Zuo & Director, 2000) the decision taken at this stage affects 80 to 85% of products' lifecycle cost. Figure 1.6 shows the general trend of determination of environmental impact and generation of impact across a product's lifecycle. From the figure, it can be observed that almost 70% of the environmental impact is determined at

design and development stage. The creative design handling the majority of the decisions at this stage is likely to have a significant effect on environmental impacting factors as well. Moreover, the ability of this phase in managing complexities at low cost makes it ideal for incorporating sustainability issues. This potential made many researchers believe that this phase can play a very critical role from sustainability viewpoint (Lin et al., 2009; Sherwin, 2004).

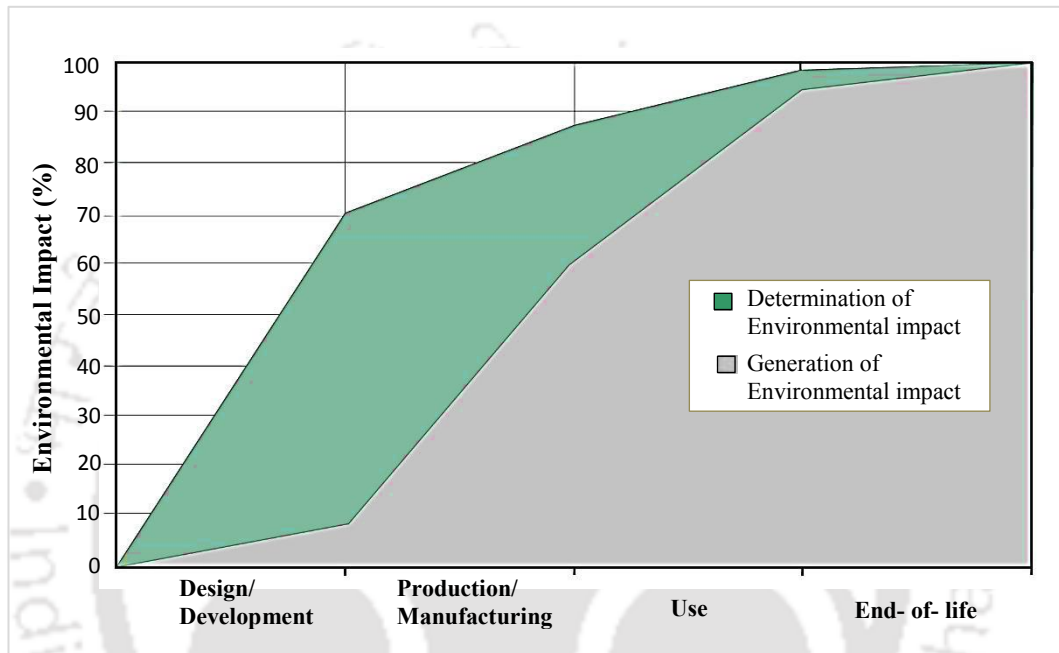


Figure 1-6: Determination and generation of environmental impact at different lifecycle stages  
Source: Adapted from Rebitzer et al. (as cited in (Kjærheim, 2013))

Despite this, limited research has been published which explores this role in incorporating sustainability, especially at practice level. The presented research broadly addresses this research gap and explores sustainability from a creative design perspective. It investigates morphological development approach as a possible method of sustainable product designing.

At this point, it is important to highlight the difference in approaches of an engineering designer and a creative designer. Literature presents very limited empirical studies concerning this difference. The presented thesis intends to fill this knowledge gap. However, based on the general approaches to designing (as discussed in Section 1.2.3, page 8 and briefed in Table 1.1), one can envisage the following differences.

1. The problem-centric approach of engineering designer is likely to limit their scope towards the effect of people (user in specific and society at large) on sustainability.

2. Engineering design is dominated by analysis and vertical thinking and that's why most of the tools and methods used by them are very focussed on the factors like Lifecycle analysis, material and manufacturing, optimisation, etc. As a result, these parameters now have the very limited scope for improvement.
3. Engineering design attempts to arrive at a single optimum solution and innovate within reality, however for issues like sustainability one need to innovate beyond parameter boundary and create new realities.
4. Engineering design lacks tools that deal with the social dimension of sustainability like the role of religion and culture in establishing sustainability. Although, literature presents a lot of references to the role of society in establishing the eco-friendly behaviour, the same is not found in their process.

The following section highlights on the research gaps addressed in this thesis.

### 1.3. Research Gaps in Creative Design for Sustainability

Previous sections (section 1.2.2, page 5; Section 1.2.4, page 10) highlighted on the general consensus among design researchers towards treating the philosophy of sustainability as an important and integral part of designing (Bovea & Pérez-Belis, 2012; Gagnon et al., 2012; Kengpol & Boonkanit, 2011; T Sakao, 2007; Vinodh & Rathod, 2010; S. A. Waage, 2007; Xing et al., 2003). In this context, McLennan (2004) advocated that sustainability should be treated as an underlying notion, and it has a tremendous potential towards informing all activities of designing (McLennan, 2004). However, literature evidences that in practice sustainability is either considered optional or an added set of constraints which generally appears in later stages of design process. It is generally considered outside creative design phase (Lin et al., 2009; Sherwin, 2004).

Previous sections also highlighted the potential of creative design phase from a sustainability perspective (as discussed in section 1.2.3, page 6 and 1.2.4, page 10). Despite this in normal practice creative designers treat sustainability parameters either optional or as an added set of constraints limiting the design space (Collado-Ruiz & Ostad-Ahmad-Ghorabi, 2010; S. Waage et al., 2005).

These discussions on research background indicated that there is a lack of understanding and integration of sustainable design philosophy, especially from a creative

design perspective. This is the main focus of this thesis and is elaborated in the form of three broad research gaps addressed in this thesis.

### 1.3.1. Sustainable Design – Lack of Comprehensive Understanding

Design literature reflects that the philosophy of sustainable design evolved as a result of broadening of scope from earlier environmental conscious philosophies like green design and eco design. However, there are many researchers who find it in close correspondence with the philosophy of sustainable development (Knight, 2009). These two different viewpoints have contributed to the varied and interpretative understanding of sustainable design, as reported in the literature (Coley & Lemon, 2009).

The philosophies of green design and eco-design were environmental-conscious concepts and according to Kjøllesdal et al., (2012) their evolution into sustainable design have created a bias towards environmental concerns. Creative designers who adopts this approach towards sustainable design are found to be limited to environmental concerns only, and does not cover the issue comprehensively (Kjøllesdal et al., 2012; Lindley, 2010). Anders Kjøllesdal (2012) accuses such designers guilty of greenwashing.

Sustainable Development as a philosophy is considered to be vague and interpretative by definition in literature (Holden & Linnerud, 2007; Kjøllesdal et al., 2012; N. Middleton et al., 1993; Wackernagel & Rees, 1996). Consequently, the understanding of sustainable design is also found to be interpretative, depending upon the area of application and field of study (Coley & Lemon, 2009). This is evident from the varied understanding and interpretations of sustainable design available in literature (Coley & Lemon, 2009). These interpretations and understandings are often communicated through various frameworks and conceptual models (Ho & Ulanowicz, 2005; Todorov & Marinova, 2011).

Moreover, the existing models and frameworks of sustainable design are either domain based or principle based, and finds limited use in the practice of creative design (Dusch et al., 2010). These models fail in pointing out the sustainability issues comprehensively, and the type of inter-relation and contradiction between them (S. Waage et al., 2005). This situation is known to create confusion for practicing creative designers in interpreting the philosophy and deciding on a possible course of action (Frisk & Larson, 2011). This is the first research gap addressed in this thesis. A knowledge gap exists in developing a comprehensive understanding of sustainable design from a creative designers' perspective. An improved framework for sustainable design is required which

can comprehensively highlight upon sustainability variables that need to be considered at the creative design phase, and the inter-relations between them.

### 1.3.2. Mental Models and Problem Solving Approaches in Practice of Sustainable Design

As pointed out in the previous research gap that the understanding of sustainable design in literature faces with ambiguity and its existing frameworks finds limited use in practice. With this background, limited studies have been conducted towards understanding the mental model and problem-solving approaches of creative designers in the practice of sustainable design.

Sustainable design is multidimensional in nature (as pointed out in section 1.2.1, page 3 and 1.2.2, page 5), but many design educators are yet to embrace this multidimensional philosophy (Lindley (2010)). Literature suggests that sustainability should be an integral part of designing, and there should not be any distinction between design and design for sustainability (Kjøllesdal et al., 2012). However, in practice the knowledge of sustainability usually stops at eco-design, material usage, carbon emission, etc. rather than considering it holistically. This situation raises doubts about the existing perceptions and mental models of novice creative designers about sustainable design imparted during design education and training.

Vanasupa and Burton (2010) stated that building a right perception and mental model of different concepts (including the contested concept of sustainable design) during design training is a critical part of design education. They posited that the mental model of reality which we consciously or unconsciously carry, reflects a lot of our actions, and deduces that it can point out the flaws in design education and training methodology. However, limited studies have been conducted towards understanding the existing mental model and problem-solving approaches of novice creative designers towards sustainability and sustainable design (Kjøllesdal et al., 2012; Lindley, 2010).

Design as a cognitive activity has been extensively studied through empirical studies and is reported in the literature (Howard et al., 2008; Taylor, Nagai, & Gero, 2012). However, limited empirical studies have been conducted towards understanding the mental model of sustainable design and how creative designers approach it in practice (Gagnon et al., 2012; Vanasupa et al., 2010). This knowledge lacuna is the second research gap addressed in this thesis. Such a study in the pretext of existing literature and

design training is expected to provide valuable information regarding the gaps in mental model of novice designers and their approaches (design morphology) towards solving sustainable design problem in practice. This study is also expected to reveal the gaps in imparting sustainable design training in a classroom.

### 1.3.3. Lack of Comprehensive Morphology for Incorporating Sustainability Issues at Creative Design Phase

Design morphology, in general, is concerned with defining “how” and “when” things should happen and in what design order (already discussed in section 1.2.3, page 6). It is considered to be very effective for training novice designers, and over a period it has become a very popular method for training and practicing designers (Howard et al., 2008). Traditionally designers were trained for designing products that satisfy human needs and aspiration, and different design morphologies were developed to support this. However, when it comes to sustainable design philosophy, the traditional design morphology popular in literature is often found to be of limited use, especially at the creative design stage.

The recently developed methods, tools and principles to support sustainable design activities are often found to support the later stages of the design process and finds limited use in creative design phase (Lewis & Gertsakis, 2001). Many researchers have indicated that creative design phase is the most appropriate stage for incorporating sustainability issues (Sherwin, 2004). There is a lack of an operational method of approaching sustainability at the creative design stage (Azkarate, Ricondo, Pérez, & Martínez, 2011; S. Waage et al., 2005). This is the third research gap addressed in this thesis. There is a need for some kind of support system which may complement designers at the creative design stage and prevents them from treating sustainability as an additional norm to be fulfilled or checked after designing is completed – almost like an afterthought. Such a support system is expected to facilitate the integration of sustainable design philosophy with creative design thinking in the mental space of a design student.

## 1.4. Research Questions, Objectives and Posits of the Study

### 1.4.1. Research Questions addressed in this Thesis

Following were the five research questions addressed in this thesis based on the research gaps identified and discussed in section 1.3 (page 12) and 2.6 (page 46). RQ1 is based on

research gap discussed in section 1.3.1 (page 13) and 2.6.1 (page 47). RQ2 and RQ3 are based on research gap discussed in section 1.3.2 (page 14) and 2.6.2 (page 48). RQ4 is focussed on research gap pointed out in section 1.3.3 (page 15) and 2.6.3 (page 49).

**RQ1:** What are the sustainable design variables that a designer need to consider at the creative design phase of the design process?

**RQ2:** What are the existing perception and mental model of novice creative designers about the concept of sustainability and sustainable design?

**RQ3:** How novice creative designers approach sustainability given a design problem in the background of their existing training and available literature?

**RQ4:** Can one evolve a support framework of sustainable design especially for the use of creative product designer based on the above research findings?

**RQ5:** How such a framework will assist a creative designer in integrating sustainable design issue with the practice of creative design?

#### 1.4.2. Objective of the Study

This research is aimed at augmenting the knowledge of sustainable design from a creative designers' perspective, and develop a morphological approach towards sustainable product designing. Following were the main objectives of this research based on the research questions stated in the previous section.

**OB1:** To develop a framework model of sustainable design highlighting on sustainability variables and the inter-relation between them.

**OB2:** To explore the existing perception and mental model of novice creative designers about the concept of 'sustainability' and 'sustainable design' in the background of their existing design training.

**OB3:** To explore the problem-solving approach of creative designers given a sustainable design problem.

**OB4:** To propose a model of sustainable design morphology to incorporate sustainability into an integrated concept in the practice of creative design.

**OB5:** To study how such morphology will affect the existing problem-solving approaches of creative designers.

### 1.4.3. Posits under Study

Following the research questions stated in section 1.4.1 (page 16), this section presents the following three posits under study.

**P1:** Existing perception and mental model of creative designers about the concept of sustainable design is biased towards the environmental dimension of sustainability.

**P2:** Existing approach of novice creative designer to sustainability given a sustainable design problem is through the environmental dimension.

**P3:** A morphological approach for sustainable product designing reveal new directions for incorporating sustainability in design (products).

### 1.5. Methodological Frame of Research

This section provides an overview of the methodology followed to answer the research questions addressed in this thesis. The whole study was conducted in 3 phases, as illustrated in Figure 1.7 and is briefly discussed in the following paragraphs

**Phase 1:** This phase of the study covered RQ1 and was focussed on exploring the various understanding and interpretations of sustainability, sustainable design and its dimensions available in the literature. Based on this exploration a comprehensive framework for sustainable design was derived. This phase employed extensive literature survey and content analysis for deriving the framework.

**Phase 2:** The second phase of the study attempted to answer RQ2, RQ3. Its focus was on exploring the perceptions and mental models of novice creative designers about the philosophy of sustainability and sustainable design. An empirical study was designed for the purpose and experiments were conducted with 70 design students from three different design schools in India. This study also attempted to explore the problem-solving approaches of novice designers when given a sustainable design problem. The study employed an instrument specially designed for the study that consisted of a questionnaire and a problem-solving exercise.

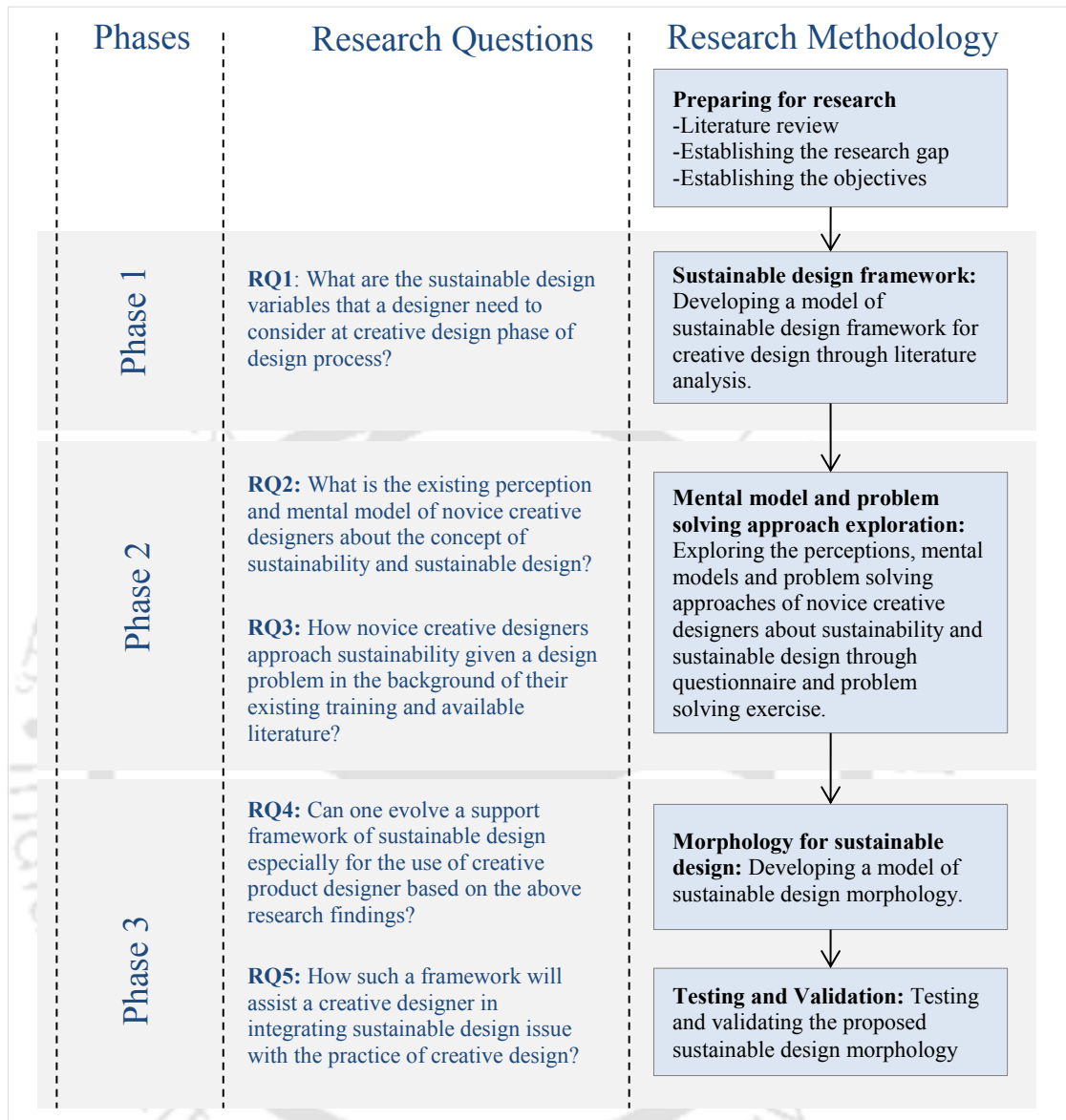


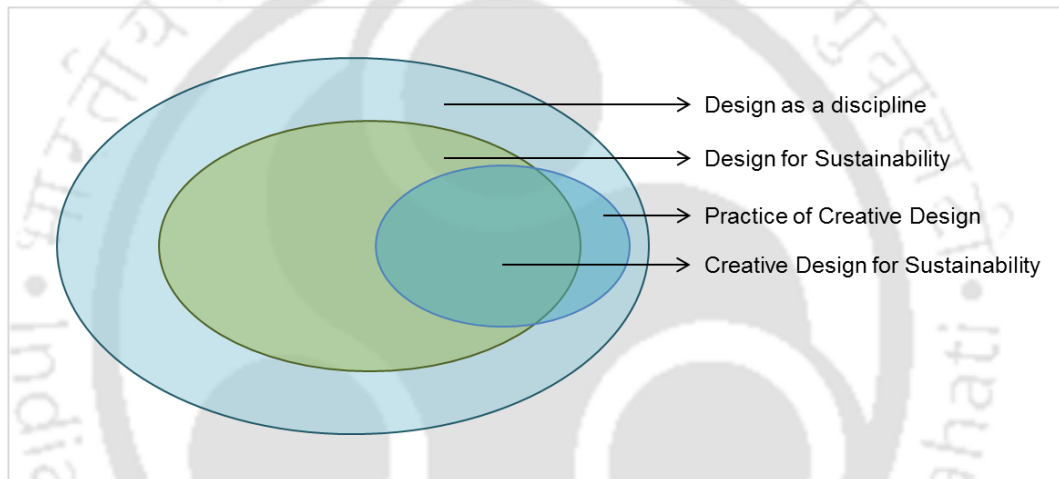
Figure 1-7: Overall methodology followed in reference to the objectives

Source: Author-generated

**Phase 3:** The third phase of the study covered RQ4 and RQ5. The first part of this phase was concerned with developing a model of sustainable design morphology based on the inferences and conclusions from Phase 1 and Phase 2 of the study. In the second part, the proposed morphology of sustainable design was tested through the dry run (using mobile phone as a sample product) and empirical study for its usefulness and comprehensiveness of incorporating sustainability issues.

## 1.6. Positioning of the Research

This research work is grounded in the philosophy of sustainable design that is considered as an underlying notion with the potential to inform all design activities. Figure 1.8 illustrates the positioning of the research in the context of design as a discipline. This research attempts to understand the implication of sustainable design philosophy on the creative design phase. The research can be seen as applied research that adopts the methodology of ‘research through design’ (Lois et al., 2011). It was aimed at generating knowledge that can be applied in the practice of design or ‘clinical research’ (Downtown, 2003).



**Figure 1-8: Positioning of the presented research**

Source: Author-generated

The audience for the outcome of this research can be anyone who is interested in sustainability and design for sustainability. However, it is mainly intended for the people involved in the practice of creative design, who aim at their designs to be sustainable. It may also be helpful for researchers who are involved in various other fields like environmental sciences, engineering, and social sciences. It can provide sufficient groundwork, based on which sustainably informed decisions can be taken by creative designers.

## 1.7. Overview of the Thesis

This research is organised into eight chapters including the current one, content of which is presented in the following paragraphs.

***Chapter 2: Exploration of Creative Design and Sustainability – A Literature Review:***

This chapter is focused on bringing relevant literature and related work on design for sustainability. It starts with literature in the practice of creative design, then studies historical evolution of sustainability concepts in design, understanding of sustainable design, existing approaches etc. the chapter concludes with the research gaps addressed in this thesis.

***Chapter 3: Framework for Research***

This chapter presents the overall methodology used to address the research questions. At first it describes the researcher's position in relation to the scientific paradigm (ontological, epistemological and methodological position) and then it presents in detail the research strategy (and associated methods, instruments used). It provides an overview of the methodological framework followed in this study highlighting on the justification and description of methods used in the study.

***Chapter 4: Developing a Framework for Sustainable Design***

This chapter is focussed on deriving a sustainable design framework based on literature analysis. The chapter came up with ten directions for sustainability highlighting on the interaction between them.

***Chapter 5: Exploring Mental Models and Approaches Adopted by Creative Designers towards Sustainability and Sustainable Designing***

This chapter focuses on understanding the existing approaches, perception and mental model of creative design about the concept of sustainability and sustainable design. The chapter reports the survey conducted through questionnaire and problem-solving exercise and attempts to highlight how sustainable design is approached in practice and what are the issues faced by a creative designer. It attempts to reflect on the mental model creative designers about the concept of sustainability and where are the gaps in understanding.

***Chapter 6: Towards Developing a Model of Sustainable Design Morphology***

This chapter proposes a model of sustainable design morphology for novice creative designers.

***Chapter 7: Validating the Proposed Morphology of Sustainable Design***

The developed morphology was validated through a dry run and an empirical study for its usefulness in incorporating sustainability issues.

### ***Chapter 8: Discussion and Conclusion***

This chapter summarises the main findings and limitations of this research. It discusses its major contributions, general implications in the field and indicates potential paths for future research.

The thesis adopted both qualitative and quantitative methods for the purpose of analysis and study. The qualitative methods are applied in cases where an in-depth understanding of designer's approaches to sustainable design is to be understood via designer's mental model. Literature searching and questionnaire was the other methods adopted for the analytical and quantitative study.



## Chapter 2

# Exploration of Creative Design and Sustainability – A Literature Review

This chapter reviews the available published literature concerning the research gap illustrated in section 1.3 (page 12). The chapter starts with a discussion on design as a field of study, significance of morphology in its practice and importance of creative design phase, in section 2.2. Section 2.3 reviews the philosophy of sustainability, its historical evolution, in general, and in design discipline. An elaborate review of sustainable design and its dimensions from various perspectives is presented in section 2.4. Next section discusses the existing approaches to incorporating sustainability philosophy in design (in industry and academic contexts). Section 2.6 revisits the research gap in the light of literature review.

## 2.1. Introduction

This chapter reviews the available published literature concerning the research gaps highlighted in Section 1.3 (page 12). The broad areas reviewed were from design science, sustainability science and the interdisciplinary area of sustainable design (Figure 2.1).

The chapter starts with an introduction to the practice of design and how structured method of designing evolved in the form of the design process (popularly recognised as the morphology of designing) in section 2.2. It also explores the practice of creative design, its morphology expressed as models, highlighting the general activities involved. Section 2.3 and 2.4 reviews sustainability and sustainable design philosophy from an evolutionary perspective and the existing understating of its dimensions available in the literature. The existing practice of sustainable design from industry as well as design education is presented in section 2.5. Toward the end, the chapter revisits the research gaps in the light of reviewed literature and concludes the chapter. Figure 2.1 illustrates how the review was conducted.

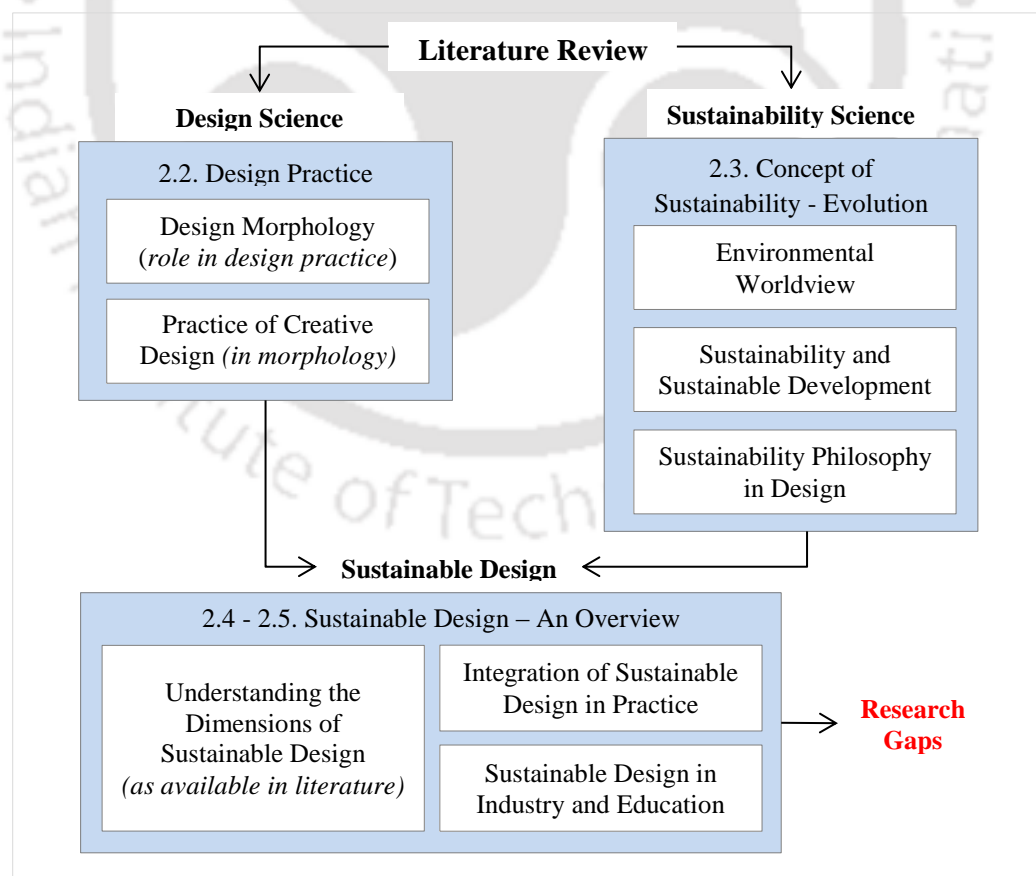


Figure 2-1: Overview of literature review

Source: Author-generated

## 2.2. Design Practice

Design is one of the most fundamental activities of human beings. Through ages, they have developed a wide range of artefacts for fulfilling their needs and wants. Need fulfilment is the primary objectives of design (Cross, 2008). The word ‘design’ often creates confusion, as in The English language there is two words ‘design’, one is a noun, and the other is a verb. John Heskett (2005) beautifully used these two different words in defining design as a field of study, as shown in figure 2.2.

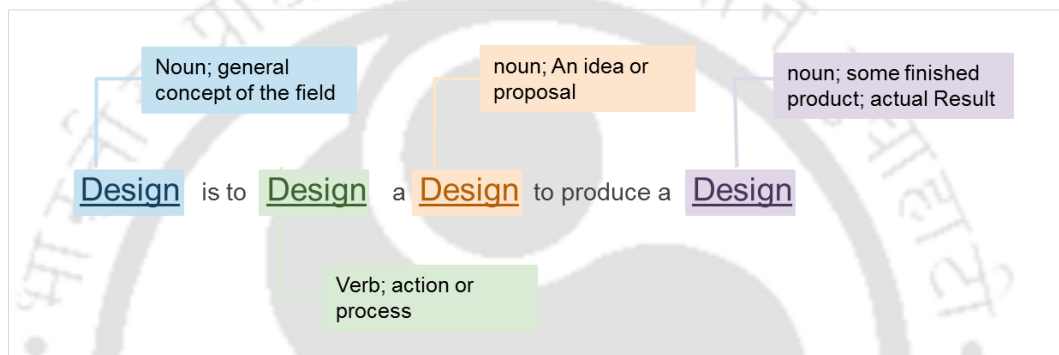


Figure 2-2: Definition of Design

Source: As given by (Heskett, 2005)

In design literature, there is no single definition or understanding of the word ‘design’ (Beltagui, Riedel, Livesey, Demian, & Moultrie, 2008; Jones, 1984). However, in this thesis it is generally used as a verb, and broadly defines it as the activity of conceiving ‘artefacts’ to satisfy human needs, wants and desire (Cross, 2008; Simon, 1996). The word ‘artefacts’ refers to the ‘world of artificial’ created by humans to make their life better (Simon, 1996).

Traditionally (in craft-based society), the activity of design included conceiving the artefacts as well as making the artefacts, both by the same person. However, with the evolution of industrial society, the complexity of artefacts considerably increased, and it became very difficult for a single person to handle all the activities. This was the time when the activities of designing were spread across various groups of people with various specialisations. One of the major demarcations was made between the activities of planning (conceiving) for what to make from the activity of actually making the artefacts. Planning became very important, and it leads the recent understanding of design and the role of a designer.

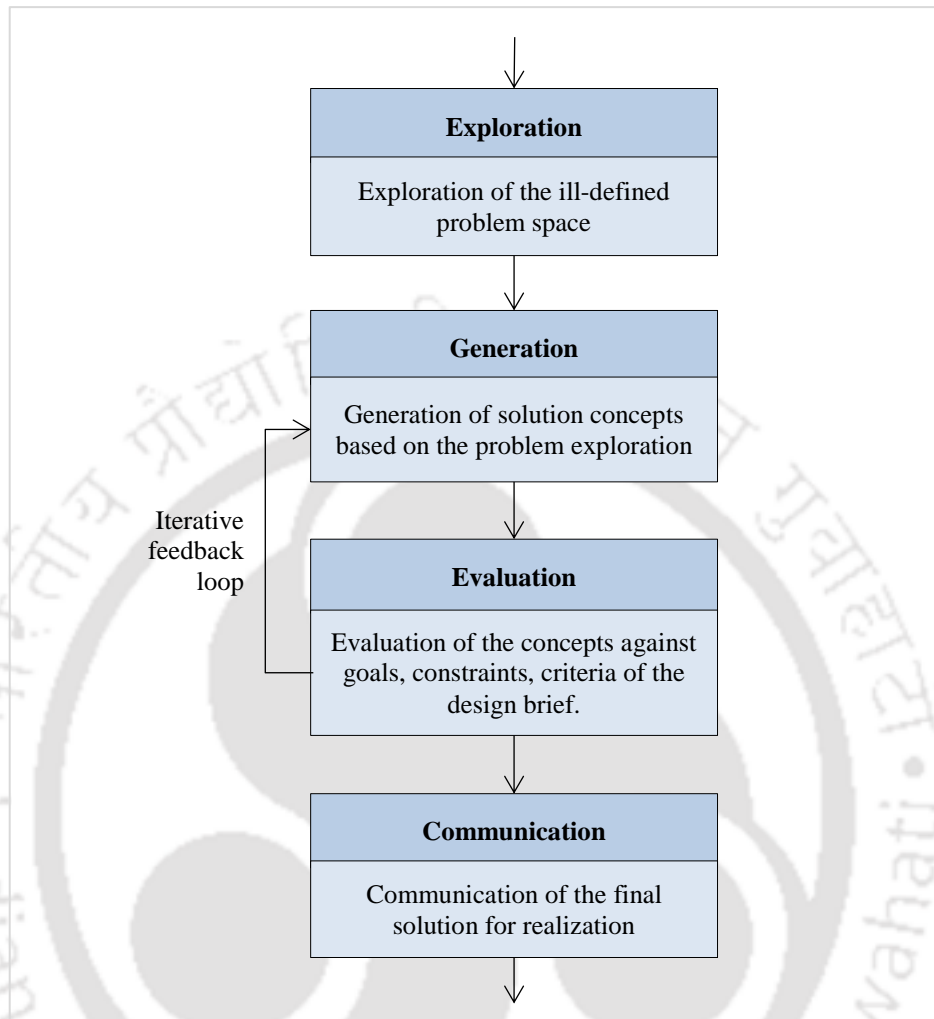


Figure 2-3: Simple four stage descriptive model of design process

Source: Adapted from (Cross, 2008)

The act of planning itself involves many steps of activities. Cross (2008) draws a simple four step descriptive model of activities (as shown in figure 2.3) that a designer perform while designing (Cross, 2008). The social, technological and economic developments of late 19<sup>th</sup> and the first half of the 20<sup>th</sup> century added more complexities to the activities of design. This was the time when the need for a more informed and methodical approach to design was felt. As a result, several (descriptive and prescriptive) models of the design process were developed to guide designers (and train the novice ones). The following section reviews the designing processes and their different models, popularly recognised as the morphology of design.

### 2.2.1. Design Morphology

Design Morphology, in general, is understood as a standard method, or a recipe capturing the essence of designing in the form of a sequence of activities. Its main objective was to develop a concrete course of action, which can be relied upon all situations; leading to successful design (Jones, 1984; Pahl & Beitz, 1999). Practically, they are concerned with the “how” and defining “when” things should happen, and in what desired order.

Over the period several models of design process evolved. Herbert Simon (1996) proposed the use of scientific methods to explore the world of man-made things (Simon, 1996). He laid importance on the role of analysis (observation) and synthesis (making) in the design process and has significantly impacted the design method discourse (Simon, 1996). These developments also led to an internal debate between designers, whether design could/should be expressed and practiced as a type of science with the reduction of emphasis on intuition.

As a result, the usefulness of design morphologies has always been debated. There are researchers who argue that while designing several variables may affect the outcome; two people can, therefore, use the same methodology and arrive at different solutions. Thus, logic and intuition interplay with one another, and is an important aspect of designing. Nigel Cross (2008) views the original design methods discussions of the 1960s as a way of integrating objective and rational methods for practicing design.

Cross (2008) classifies the various models of the design process into descriptive and prescriptive models. Descriptive models attempt to describe the process of design and identifies the significance of generating a solution concept early in the process. This reflects the ‘solution-focussed’ nature of design thinking. Prescriptive models on the other hand usually offer a more algorithmic, systematic procedure to follow, and prescribes designers with the steps to be followed. An example of a descriptive model proposed by French (1999) and a prescriptive model proposed by Archer (1984) is shown in Figure 2.4.

Howard, Culley and Dekoninck (2008) did a comparative analysis of 27 design morphologies proposed by different authors and found them in general agreement. The most common phases across morphologies were ‘analysis of task’, ‘conceptual design’, ‘embodiment design’, and ‘detailed design’. Apart from these four phases were ‘establishing the need’ preceding the ‘analysis of task’ and ‘implementation phase’ followed by ‘detailed design’ (Howard et al., 2008). Although, many researchers doubts

the usefulness of design morphology in coming up with successful design solutions, it is considered to be very effective for teaching novice designers and managing design projects (Howard et al., 2008). Empirical studies have shown that the use of more 'efficient' design process correlated positively with both the quantity and quality of students' design result (Radcliffe & Lee, 1989). Pahl and Beitz (1999) suggest that to carry out design effectively and efficiently, methodological support is crucial. Various studies in design education have shown that a systematic approach can be helpful for students and novice designers (Cross, 2008).

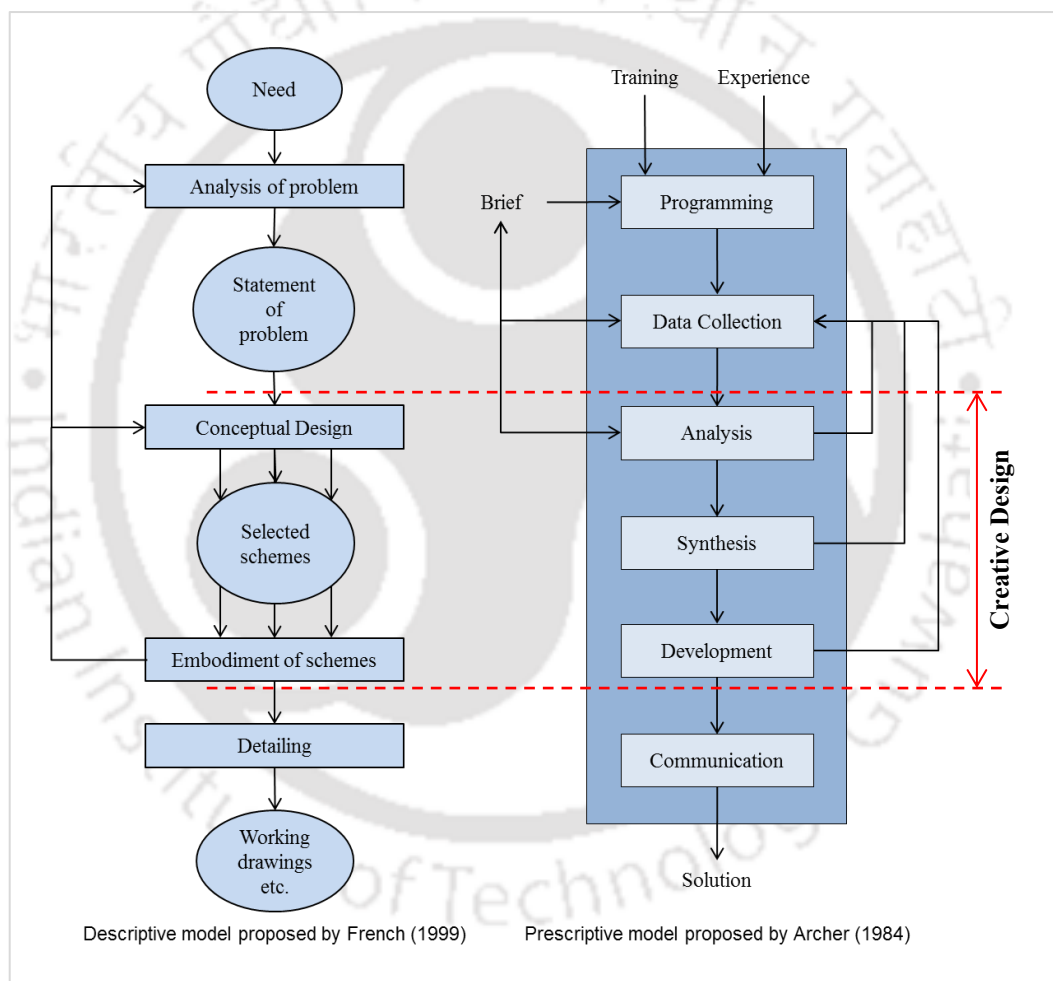


Figure 2-4: Descriptive and prescriptive models of design process

Source: As classified by (Cross, 2008)

This discussion establishes the importance of morphological support in design practice, especially for training novice designers. The discussion also revealed that there is a general agreement among different design morphologies regarding the steps/phases to be followed. This reflection is the reason this thesis attempts to study the morphological

development approach for solving sustainability related issues. Among these various steps/phases, the creative design phase has been identified to be most important by many researchers (S. Waage et al., 2005; Zuo & Director, 2000). The following section elaborates on this phase.

### 2.2.2. Practice of Creative Design

The word creativity in general involves generation of ideas that are novel and appropriate (Boden, 1995; Goldschmidt & Tassa, 2005; Kampylis, Berki, & Saariluoma, 2009; Nguyen & Shanks, 2009). In design, it involves the production of novel and useful products (Mumford, 2003). The phrase ‘creative design’ thus can be broadly understood as the process of creating a novel and useful ‘artefact’ to satisfy human needs, wants and desires.

In design morphology (discussed in section 2.2.1, page 26) the conceptual design phase has been identified as the most creative phase of design. At this stage, 70 to 80 percent of the most important decisions are taken (Cross, 2008). Howard et al. (2008) while comparing various design morphologies found that the phases of conceptual design and embodiment design put together closely corresponds with the creative processes described in cognitive psychology (Howard et al., 2008). That is why this part of design morphology is often referred as the creative phase of design or simply ‘creative design’. Figure 2.4 points out this phase in two popular models of the design process.

Conceptual design is where high-level abstract solutions are created. Zuo and Director (2000) proposed a model of the conceptual design illustrated in Figure 2.5. The model consisted of three iterative design cycles namely problem definition, issue resolution and concept formation. Problem definition is concerned with analysing the problem describing it (in terms of specifications, performance requirement, restrictions, etc.). Issue resolution is the process identifying the issue and making decisions which involves choosing one from the options available. Concept formation is where the forms are described and evaluated. Embodiment design phase takes the principle solution or concept developed in the conceptual design phase, select the most appropriate option and develop it further in the light of technical and economic criteria.

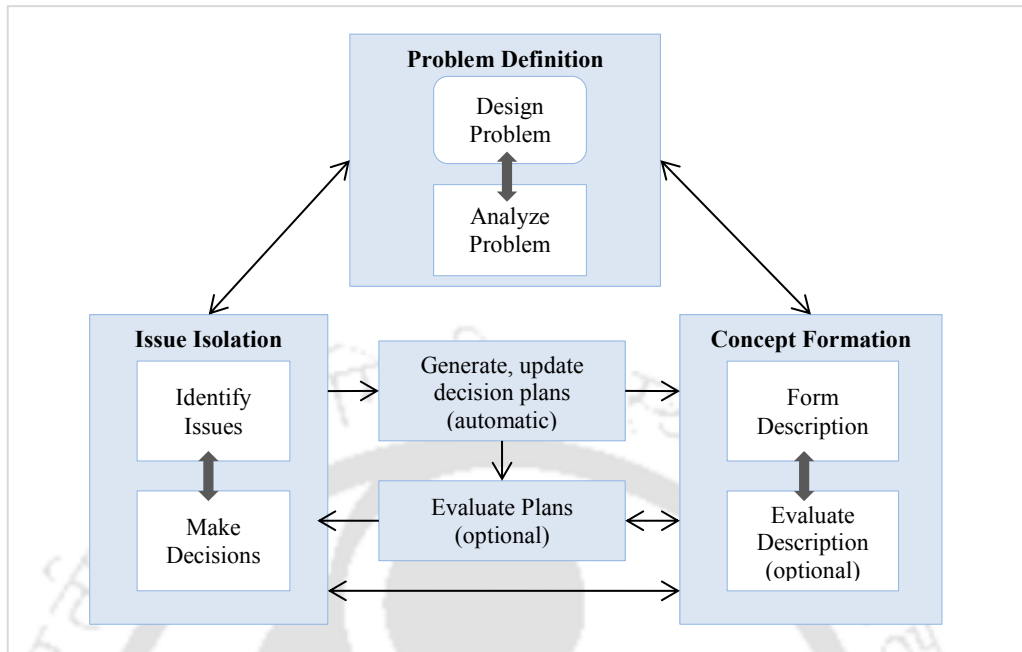


Figure 2-5: Model for Conceptual Design Process  
Source: (Zuo & Director, 2000)

Within creative design phase, a designer starts with a poorly defined problem. As they proceed they acquire more and more information about the problem, analyses it, understands it, and slowly proceeds toward a better understanding of the problem and the solution to be designed. The process of solution exploration happens with problem exploration, and the problem is explored by providing alternate solutions. This process continues depending upon the available time and resource. A designer stops with the most appropriate solution to the problem.

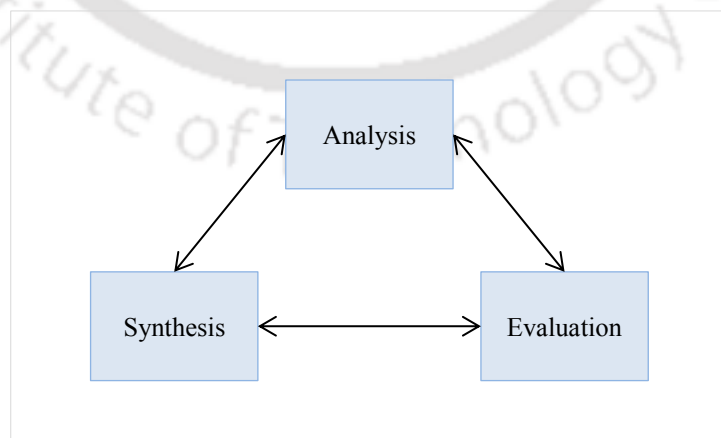


Figure 2-6: Analysis-synthesis-evaluation model of creative design  
Source: Adapted from (Jones, 1984) and redrawn

Creative design phase had attracted a lot of attention in the past from many researchers, most of which were focussed on understanding the cognitive mechanism behind it, and developing support tools to augment the power of designers (Cross, 2008; Taylor et al., 2012). However Howard et al. (2008) observed that over a period of time there has been a shift from describing the creative processes as subconscious cognitive phases to more of activity based phases. The process includes all the three phases of analysis, generation and evaluation (Howard et al., 2008). Jones (1984) proposed the analysis – synthesis – evaluation structure of the creative design process that is shown in Figure 2.6. Table 2-1 enlists general activities/actions to be performed during the creative design phase.

**Table 2-1: General activities of creative design**

Source: Author-generated based on Zuo & Director (2000) model of conceptual design

| <b>Phases of Creative Design</b> | <b>Activities involved</b>   |
|----------------------------------|--|
| <b>Analysis</b>                  | 1. Analyse problem<br>2. Identify issues<br>3. Make decisions                              |
| <b>Synthesis</b>                 | 4. Generate, update decision plans<br>5. Form Description                                  |
| <b>Evaluation</b>                | 6. Evaluate Description<br>7. Select the most appropriate solution and develop it further. |

The creative design phase is often attributed to the heart of the design morphology. The decisions taken at this stage handles up to 85% of the life cycle cost of products (Cross, 2008; S. Waage et al., 2005; Zuo & Director, 2000). Moreover, this stage provides a lot of freedom for modification at low cost compared to the further stages of the design process (as illustrated in Figure 1.5, page 10). These attributes have made this phase very critical in solving complex technical problems (Carayannis & Coleman, 2005; Naes & Nyvold, 2004; Taylor, 2009).

In recent years, sustainability consideration by designers has evolved as a major concern in design research and practice. Sustainability parameters are expected to add to the complexity of designing, and many researchers believe that the creative design phase has great potential. The following section presents a review of the evolution of sustainability and its implications in the field of design.

## 2.3. Concept of Sustainability – Evolution

The term ‘Sustainability’ was first used by Von Carlowitz (1713) in the context of forest industry management (Dusch et al., 2010). However, the current conception of sustainability is rooted in environmentalism and world views, as discussed in the following section.

### 2.3.1. Environmental World Views

Environmental worldview mainly discusses the relationship of human beings with their environment and ecology. Literature presents many views on this relationship as reviewed by Dusche, Crilly and Moultrie (2010). Dusche et al. (2010) make a distinction between these worldviews into the ‘conservative-nurturing’ and the ‘radical-manipulative’ world views that are contradictory in nature (Dusch et al., 2010).

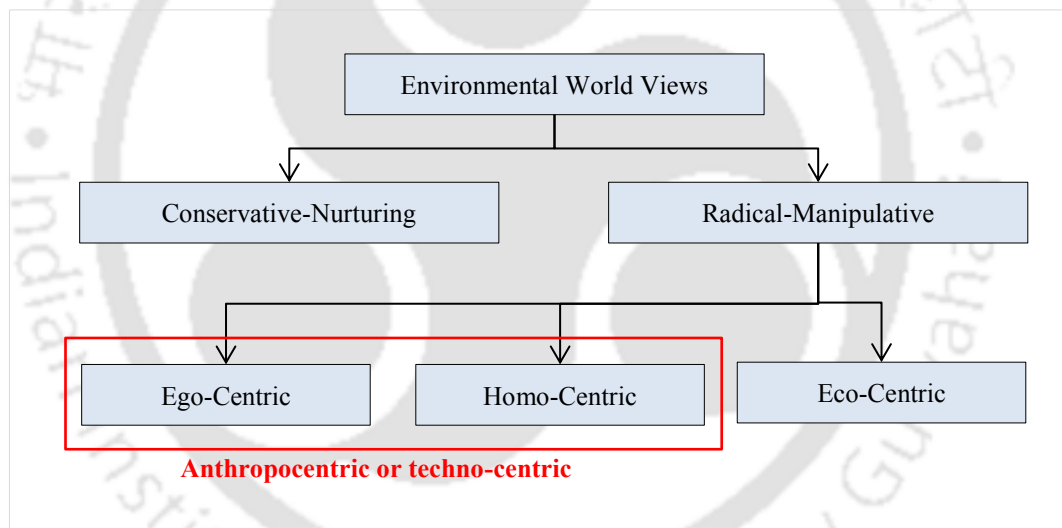


Figure 2-7: Classification of environmentalism world views

Source: Author-generated based on (Dusch et al., 2010) classification

The conservative-nurturing world view regards humans as part of nature, considering environment to be the focus of attention. Whereas, radical-manipulative views is based on the belief that humankind has not only the right but also the obligation to shape the world in order to create a better place. Radical-manipulative is further differentiated into ego-centric, homo-centric and eco-centric views (Merchant, 1992). Ego-centric and homo-centric together is often referred as anthropocentric or techno-centric (Dusch et al., 2010) as shown in Figure 2.7. Similar classifications were also made by O’Riordan (1989) and Pearce (1993). The current conception of sustainability as a philosophy carries an anthropocentric world view as discussed below.

### 2.3.2. Sustainability and Sustainable Development

The main aim of sustainability is to maintain certain quo in nature for the sustenance of resources (Dusch et al., 2010). It evolved with the realisation that the Earth's carrying capacity is limited, and cannot sustain the existing trend of consumerism based development. This has already been illustrated in Figure 1.1 (page 4) which shows the trend of increasing ecological footprint. If this trend of consumption continues, by the year 2050 we will require the resources of more than two Earth to sustain our lifestyle (WWF, 2010). Such a situation can only be avoided through sustainable utilisation of resources, and by maintaining a certain status quo in nature (IUCN, 1980). Reducing the resource consumption rate within the Earth's sustainable limits and maintaining it for a very long time is thus the primary objective of sustainability.

In 1987, Brundtland Commission proposed the philosophy of 'Sustainable Development' aimed towards achieving sustainability. Within a short period, various models and framework of sustainable development were proposed in the literature, out of which the triple-bottom-line model (3BL) was found to be most popular. This model dictates the consideration of three broad dimensions of sustainability namely environment (planet), society (people) and economy (profit) (Elkington, 1994). These dimensions of sustainability are often denoted as pillars of sustainability. It reflects that a sustainable development requires consideration of natural (planet), human (people), and economic (profit) capital (Kajikawa, 2008; Schoolman, Guest, Bush, & Bell, 2011). Figure 2.8 shows two most popular models of sustainable development.

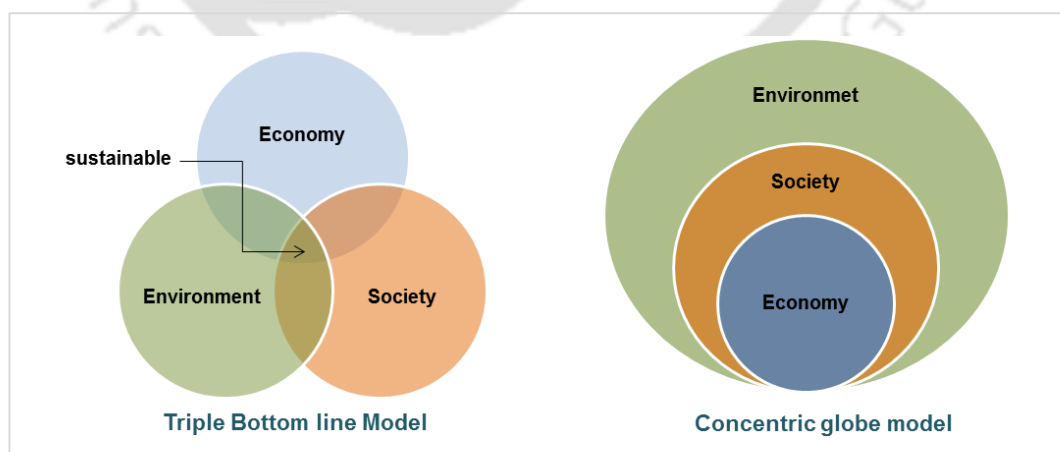


Figure 2-8: Models of sustainable development

Source: Adapted from models available in literature (Elkington, 1994)

The philosophy of sustainable development defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). This definition is often criticized to be generic, ambiguous and open to interpretations (Holden & Linnerud, 2007; N. Middleton et al., 1993; Wackernagel & Rees, 1996). Despite this, there is a general consensus among researchers towards incorporating it into the activities of governments, organisations, industries, communities and society as a whole (Gagnon et al., 2012; Kjøllesdal et al., 2012).

In recent years, various disciplines and field of study have adopted this philosophy in an attempt to align their practices towards sustainable development. The discipline of design is one of them. The following section elaborates on the emergence of sustainability in design.

### 2.3.3. Sustainability Philosophy in Design

The environmental concern that is the genesis of sustainability started evolving in design discipline during the 1960s and 1970s with growing public concerns about the dangers of pesticides to both ecosystem and humankind. ‘Green’ movement started during the 1970s which led to the establishment of Greenpeace. The first energy crises occurred during the same time, alerting people about the limited nature of earth’s resources. In a very short time, it became apparent that the conventional practices of production and consumption have deeper influences other than environmental pollution (Walker, 2002). The conventional practice of design was questioned and the quest for different ways of doing and making things started. Victor Papanek (1971) was among the few pioneers of that time, who started examining ways of making products that used less energy, and can be made from recycled materials.

The environmental crises, of the 1980s and 1990s including Bhopal and Chernobyl, resulted in the introduction of environmental and safety legislation. The public became more environmentally conscious, and designers were motivated to produce “environmentally friendly” products. The Green Consumer Guide published in 1988 became a useful resource for environmentally concerned citizens. The concepts of green design and eco-design were coined for environmentally conscious design. Green design described a process of dealing with individual environmental impacts whereas, eco-design dealt with environmental impacts over a product’s entire lifespan.

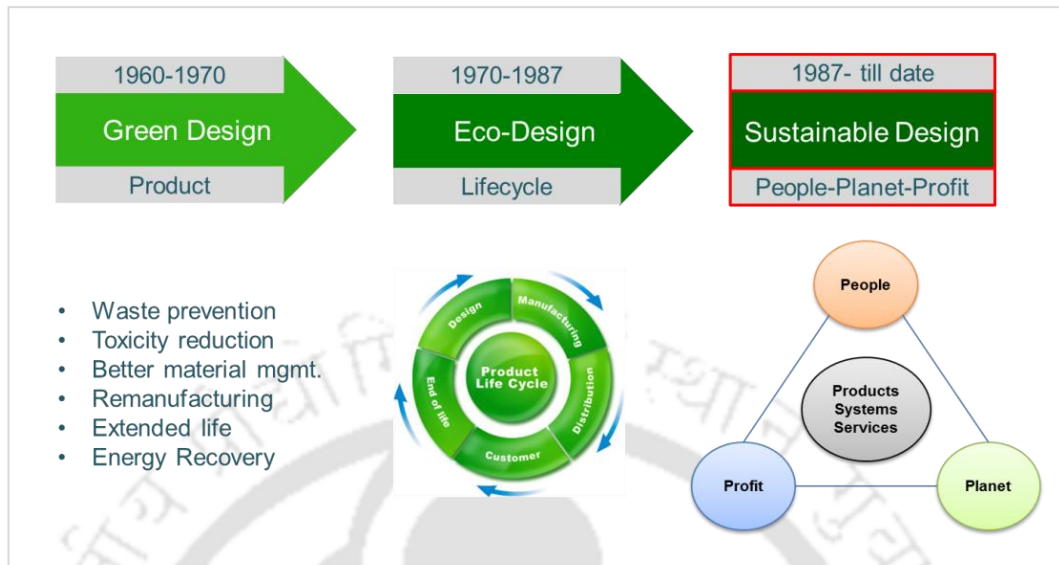


Figure 2-9: Evolution of sustainable design through green design and eco-design.

Source: Author-generated

The development of the latter half of the 1980s made it apparent that the effort concerning environmental impact alone is not sufficient (Walker, 2002). During the same time, the philosophy of ‘Sustainable Development’ was proposed by Brundtland Commission (already discussed in section 2.3.2, page 32). The implication of this philosophy in design led to the evolution of Sustainable Design. It intends to conceive products, processes, and services that meet the needs of society while striking a balance between economic and environmental interests (ECFSE, 1999). Owing to close correspondence with sustainable development philosophy, the sustainable design itself constituted the three broad dimensions of the environment (planet), society (people) and economy (profit). This evolution over the period is summarised in figure 2.8. The following section further elaborates on this evolution and presents a review sustainable design and its dimensions.

## 2.4.Sustainable Design – An Overview

The philosophy of sustainable design is not seen as a new philosophy of design discipline, rather it is seen as the continuation of the previous environmental conscious concepts (as observed in previous section 2.3.3, page 33). In design literature, it is often seen as a broadening of scope from green design (product level) to eco-design (life cycle level) to sustainable design (system level). However, there are many researchers who see it as a philosophy in close correspondence with sustainable development and associate society

and the economy as an integral dimension of sustainable design. This thesis argues that both these point of views have contributed to the current conception of sustainable design and summarised it Figure 2.10.

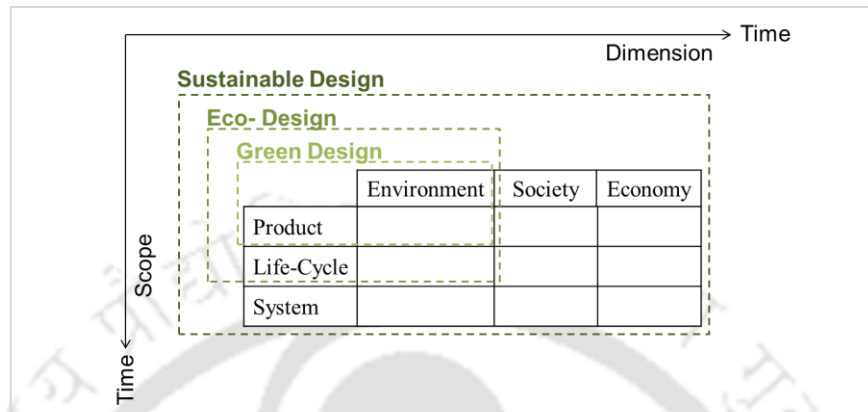


Figure 2-10: Sustainable Design – evolution through time in relation to related concepts

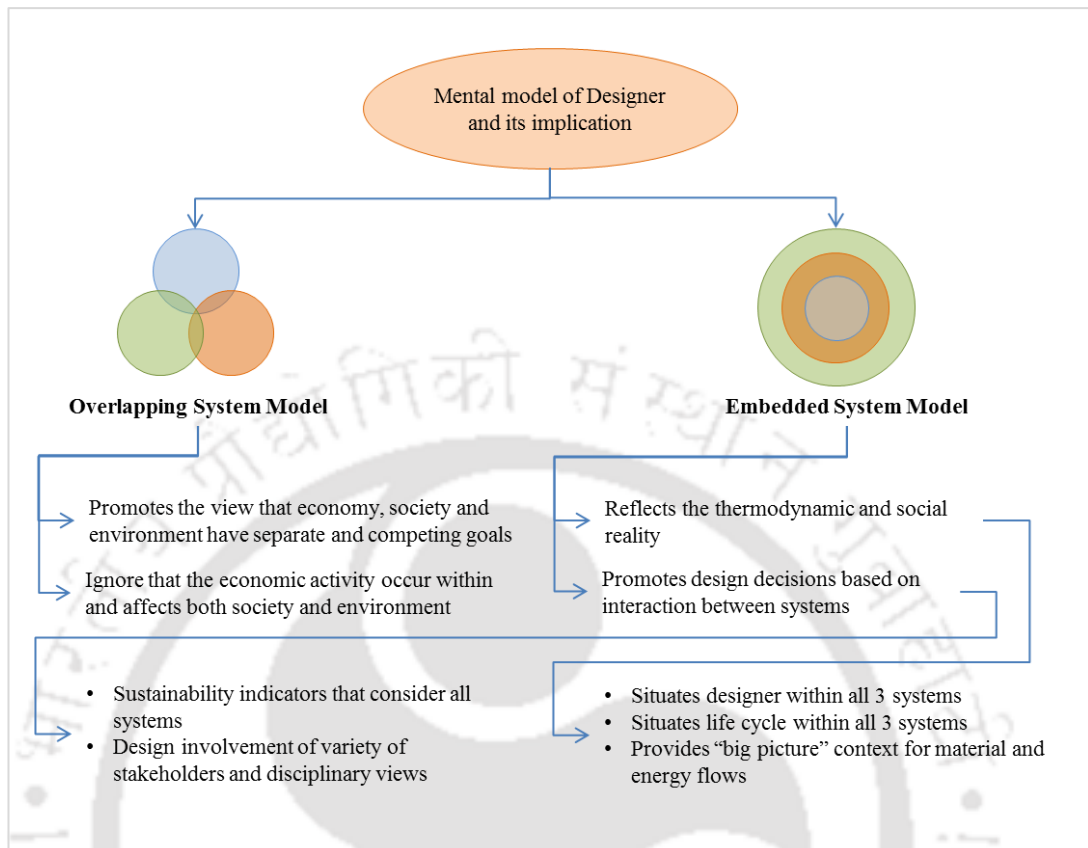
Source: Author-generated based on consolidated findings from literature

The figure presents a comprehensive understanding of sustainable design in relation to the environmental-conscious philosophies of green design and eco-design. The environmental issues at the product level (interacting space between product and environment) represent the concept of green design. The issues concerning environment at lifecycle level (interacting space between lifecycle and environment) represents eco-design. The matrix as a whole (including societal and economic parameters) represents the comprehensive philosophy of sustainable design.

The product environment and lifecycle-environment concerns have been well studied in literature, however, to understand sustainable design comprehensively; the implication of other cells needs to be understood. In existing literature, its understanding is fragmented and in its evolutionary stages. The following section presents a review of these fragments from different sources and field of study.

#### 2.4.1. Understanding the Dimensions of Sustainable Design

Literature presents numerous definitions and interpretations of sustainable design from various authors (Ulanowicz, 2005; Fiona, 2009) which largely depends on the field of study and area of application (Ho & Ulanowicz, 2005; Todorov & Marinova, 2011). Despite this variation, owing to close correspondence with sustainable development, there is an agreement in terms of its dimension (i.e. environment, society and economy). In general, the sustainable design employs the framework (or model) of sustainable development, two of which has already been illustrated in Figure 2.8 (page 32).



**Figure 2-11: Models of sustainability and its implication**  
 Source: Adapted and redrawn from (Vanasupa et al., 2010)

Vanasupa and Burton (2010) points out that overlapping system model (weak model) promotes the view that the economy, society and environment have competing goals, and sustainability is about balancing them. Whereas, the embedded system model propagates that economy is a part of the society that is a part of environment. They suggest that the concentric globe model (strong model) or embedded system model is more suited for designers and engineers (Vanasupa et al., 2010). Figure 2.11 presents the implication of both the models on designers' decision making (adapted and redrawn from (Vanasupa et al., 2010)).

The following sections attempts to review the fragmented understanding of sustainability and its dimensions, as discussed in section 2.4 (page 34).

#### 2.4.1.1. *Environmental Dimension of Sustainability*

Historically, the environmental dimension of sustainability is rooted in the philosophy of environmental worldviews, already discussed in section 2.3.1 (page 31). Depending upon what worldview is accepted, the understanding of environmental sustainability may vary. However, the most accepted set of definitions carry an anthropocentric or techno-centric

world views. It is based on the belief that humankind not only has the right, but also an obligation to shape the world in order to create a better place and is aimed at maintain a certain quo in nature for sustenance of resources (Dusch et al., 2010).

According to Goodland (1995) environmental sustainability “seeks to improve human welfare by protecting the sources of raw materials (both renewable and non-renewable) used for human needs and ensuring that the sinks for human wastes are not exceeded, in order to prevent harm to humans”. He set constraints for “the use of renewable and non-renewable resources on the source side, and pollution and waste assimilation on the sink side”.

On similar lines, OECD environmental strategy for the first decade of the 21<sup>st</sup> century lays down four criteria for environmental sustainability (OECD, 2001).

1. **Regeneration**- Renewable resources to be used efficiently and their use should not exceed their long-term rates of natural regeneration.
2. **Substitutability**- Non-renewable resources to be used efficiently limited to levels that can be offset by substitution with renewable resources.
3. **Assimilation**- Releases of hazardous or polluting substances into the environment should not exceed their assimilative capacity.
4. **Avoiding irreversibility**- Activities that may cause irreversible damage to the environment should be avoided.

Environmental sustainability is also defined by many researchers based on the bio-geophysical aspect (Holdren, Daily, & Ehrlich, 1995). For example, Holdren et al. (1995) define it, as maintenance and improvement of the integrity of the Earth’s life-supporting systems (Holdren et al., 1995). This includes the preservation of biological diversity, and biogeochemical integrity of the biosphere through conservation and proper use of air, water and land resources. Sutton (2004) defined environmental sustainability as “the ability to maintain the qualities that are valued in the physical environment” (Sutton, 2004). The recent understanding of environmental sustainability based on bio-geophysical aspect is focused on the following six systems (Moldan, Janoušková, & Hák, 2012).

1. **Climate systems** - covering climate and climate change, climate risk management, mitigation and adaptation.
2. **Human settlements and habitats** - covering cities, urbanization and transport.
3. **Energy systems** - covering energy use, energy conservation, renewable energy, energy efficiency and bioenergy.

4. **Terrestrial systems** - covering natural and managed ecosystems, forestry, food systems, biodiversity and ecosystem services.
5. **Carbon and nitrogen cycles** - covering sources and sinks, feedback processes and links to other systems.
6. **Aquatic systems** - covering marine and freshwater ecosystems, fisheries, currents and biodiversity.

In this regard, the Millennium Ecosystem Assessment Project suggests four categories of ecosystem services (Millennium Ecosystem Assessment, 2005; Moldan et al., 2012).

1. **Provisioning** - food, fresh water, wood and fibre, fuel, etc.
2. **Regulatory** - climate regulation, flood regulation, disease regulation, water purification, etc.
3. **Cultural** - aesthetic, spiritual, educational, recreational, etc.
4. **Supporting** - nutrient cycling, soil formation, primary production, etc.

Based on the report of OECD (2001) and Moldan (2009), Moldan et al. (2012) extract the following objectives for environmental sustainability.

1. **Maintaining** the integrity of ecosystems through the efficient management of natural resources.
2. **Decoupling** environmental pressures from economic growth.
3. **Improving information for decision-making** - measuring progress through indicators.
4. **The social and environmental interface** - enhancing the quality of life.
5. **Global environmental interdependence**- improving governance and co-operation.
6. **Long-term perspective** (without any designated time limit).
7. **Understanding of the non-linear evolution** of complex systems (tipping points, thresholds, sudden, unpredictable changes)
8. **Taking feedbacks** into account (in particular the positive ones)
9. **Regard for different scales** (in time and space)
10. **Flexibility**- the ability to react to a changing situation, learning by doing.
11. **Key importance of local conditions**, and
12. **Respect for living nature** in general and for biological diversity in particular.

At this point, it is important to note that most of these definitions and understanding of environmental sustainability comes from disciplines like environmental science, ecology, etc. and not from design. As a result, creative designers find these definitions of limited use in practice. Say for example a designer has been given the task of designing a mobile phone. The OECD (2001) list of objectives seems to be very broad and at a system level. The Millennium Ecosystem Assessment Project, which suggests four categories of ecosystem services is too vague to be applied at product design level. Moreover, the ecological system model may not be very fruitful in deciding upon the strategy of how to achieve sustainability in designing the given product. Thus, it can be observed that most of the definitions and understanding of environmental sustainability discussed above are of limited use in product design.

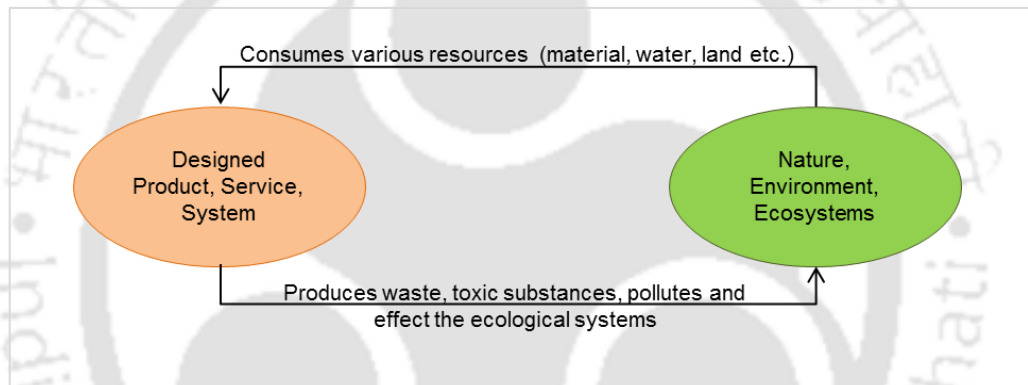


Figure 2-12: Fundamental understanding of environmental sustainability

Source: Author-generated based on reviewed literature

The most fundamental understanding of environmental sustainability comes from the fact that the Earth's capacity to support human needs wants and desire is limited, beyond which it cannot sustain our lifestyle. Thus, for sustainability one need to maintain a certain quo in nature for the sustenance of resources (Dusch et al., 2010). The designed products, services, systems consume resources (like material, water, land, etc.) and during various phases of lifecycle (like manufacture, use, disposal etc.) produces waste, pollution and affects the ecological systems. To maintain certain status quo in nature the rate of resources consumption need to be within the regeneration capacity of Earth and the waste, pollution generated should be within the assimilative capacity. Based on this understanding, a simple model of direction for environmental sustainability can be summarised as shown in Figure 2.12.

#### 2.4.1.2. *Social Dimension of Sustainability*

Social sustainability is primarily focussed on the development of people in the positive direction. It can only be achieved by fulfilling the basic as well as higher order needs of the both the present and future generation. In literature, there are varying understanding of social sustainability depending upon the point of view and the area of application. These varied understanding of social sustainability was reviewed and classified by Vallance, Perkins, & Dixon (2011) into three directions. The presented thesis adopts their work and uses their direction of social sustainability, as illustrated in Figure 2.13.

1. **Development Social Sustainability:** This direction of social sustainability is concerned with the fulfilment of the basic and higher order needs of human beings. Basic needs consist of both tangible needs such as pure air, potable water, healthy food, housing, health and medication, basic infrastructure and services, energy, sanitation etc. and intangible needs such as equity in access to resources and power, freedom, education, employment, justice, access to influential decision making etc. The higher order needs include building the social capital and cohesion and removing social exclusion. It also includes general capital building, merging environmental and economic needs, conserving and enhancing resource base, sustainable level of population, reorienting technology and managing risks. From a design perspective development sustainability concerns designing products, services and systems that fulfil the needs of the users in particular and society as a whole without negating any of the criteria mentioned above.
2. **Bridge Social Sustainability:** Bridge social sustainability is concerned with building better relationships between people and their biophysical environment through eco-friendly behaviour and stronger environmental ethics. It harnesses the human potential to generate improved environmental outcomes. Its approaches can be non-transformative like adoption of new technological innovations, banning CFCs, provision of recycling facilities, creating awareness and providing information on how one can improve environment etc. or transformative which challenges the fundamental ways in which the environment is socially constructed. From a design perspective, it's about designing products, systems and services that promote eco-friendly behaviour sensitise people towards environmental protection, building ethical responsibilities for ecology, etc.

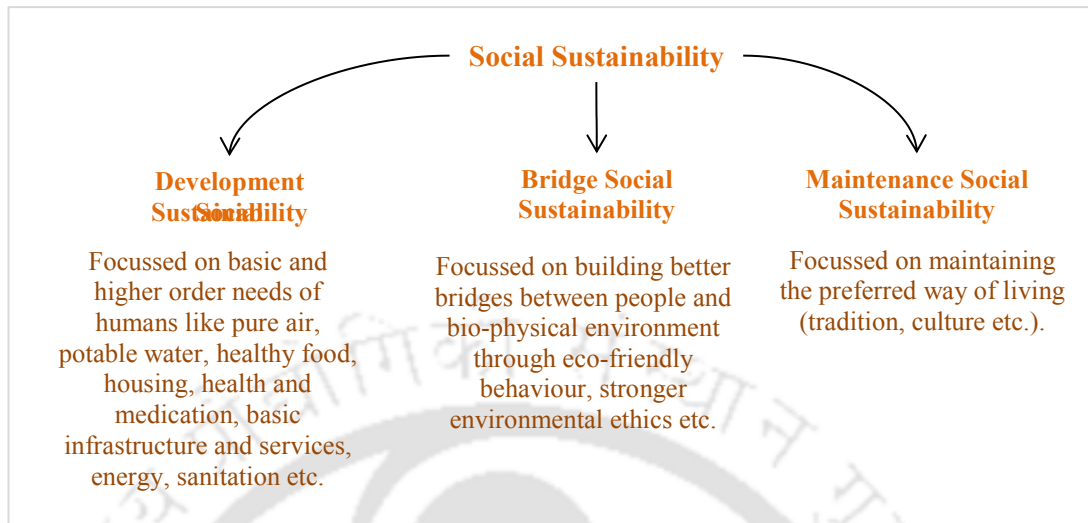


Figure 2-13: The three major directions of social sustainability.

Source: Based on the review and classification done by (Vallance et al., 2011)

3. **Maintenance Social Sustainability:** Maintenance Social Sustainability advocates maintaining the tradition, practices, preferences and places that people would like to be maintained (sustained) or improved. It deals with the way in which social and cultural preferences, its characteristics and environment are maintained over a period. From a design perspective, it's about designing products, systems and services that complement the cultural, traditional, religious practices that people would like to be maintained.

#### 2.4.1.3. *Economic Dimension of Sustainability*

Economic Sustainability, in general, is defined as the ability of an economy to support a defined level of economic production indefinitely (thwink.org, 2014). It is often used to identify strategies that facilitate the use of available resources in the best way possible for greater advantage. It is aimed at promoting the use of resources in both efficient and responsible way, such that it can sustain long-term benefits or profits without creating environmental concerns or impairing the balance of local ecology (wiseGEEK, 2014). Selection of raw materials that are more environmentally friendly, designing waste disposal strategy that does not damage the local environment and community, promotion of community investment, remaining a viable option for a long period are few of the examples of strategy for economic sustainability. Long term profitability for all the stakeholders (owner, employee, community, etc.) and self-amplifying growth is an important goal of a sustainable economy.

According to World Bank (2006) report titled “where is the wealth of nations?” development of various capitals (like man-made capital, social capital, natural capital, etc.) is attributed as economic sustainability (World Bank, 2006).

1. **Man-made capital** development includes wealth creation as in money or property owned or accumulated for the production of more wealth. It also includes the development of physical infrastructure, a physical manifestation of information, techniques, knowledge, etc. which are necessary ingredients for the production of goods and services. The wealth as in money or property, owned, or accumulated which is available for use in the production of more wealth. It also includes physical infrastructures, a physical manifestation of information, techniques, and knowledge required to produce goods and services.
2. **Natural capital** consists of land, air, water, living organism, and all other natural resources that have the potential for goods and services for human wellbeing and survival. These resources form the basis of all human economic activities, and its development through efficient and responsible use contributes towards sustainability.
3. **Social capital** concerns various attributes of the society such as the quantity and quality of social interactions, relationship building institutions, social cohesion, etc. whereas human capital refers to the stock of competencies, knowledge, habits, social and personality attributes, including creativity, cognitive abilities, embodied in the ability to perform labour so as to produce economic value. It is also connected with education, productivity, growth, and innovation (Michael, 2013).

A sustainable economy is also defined as an economy that provides monetary resources necessary and generates enough capital necessary for growth and support of the current needs of the community (wiseGEEK, 2014). Some of the indicators include the creation of sufficient jobs, products, services, distribution of wealth, poverty level, the cost of living, employment rate, etc.

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## 2.5. Integration of Sustainable Design in Practice

As highlighted in Chapter 1 (Section 1.1, page 1 and Section 1.3, page 13) design literature reflects a growing consensus (among design researchers, creative designers, users, consumers, organisations etc.) over integrating the philosophy of sustainability with the practice of designing. In recent years this consensus was manifested with the newly evolved philosophy of sustainable design, which is recommended to be treated as an integral part of designing (Bovea & Pérez-Belis, 2012; Gagnon et al., 2012; Kengpol & Boonkanit, 2011; T Sakao, 2007; Vinodh & Rathod, 2010; S. A. Waage, 2007; Xing et al., 2003). The presented thesis builds on this consensus and attempts to develop a morphological approach towards designing sustainable products. This section reviews the literature concerning the integration of sustainability philosophy with the practice of designing in the context of industry (section 2.5.1) as well as education (section 2.5.2).

### 2.5.1. Industrial Practice of Sustainable Design

Literature presented limited publication concerning the sustainable design practice in the industry. Sherwin (2004) was among the first designers to share his experience of designing in the industry. He pointed out that sustainability issues come into picture only in the later stages of the design process. He advocated that sustainability consideration should start to form the initial phases of designing, especially creative design phase. Other researchers like Lin et al. (2009) also supported his views, and pointed out that the tradition practice of creative design in industry is mainly focused on factors like consumer preferences, product functionality, etc. neglecting the sustainability aspects of the product. Creative design phase is undeniably the important phase of designing (as discussed in section 2.2.2, page 28), but industrial practice of sustainability is not well integrated with this phase (Lin et al., 2009). However, recent research papers indicates that the industry have recognised its potential and are attempting to build tools and methods to support sustainable design at creative phase (Bovea & Pérez-Belis, 2012; Kengpol & Boonkanit, 2011; Shin, Jun, Kiritsis, & Xirouchakis, 2011).

Apart from the lack of sustainability consideration in the initial phase of design, the other characteristics of industry practice are their bias towards the environmental dimension. As elaborated in Section 2.4 (page 34), sustainability is a multidimensional philosophy including the dimensions of environment, society and economy and should be considered at multiple levels (product, lifecycle, system). Literature review reflected that most of the approaches adopted by industry in focussed on achieving environmental efficiency and not much concern is towards the social and ethical responsibilities (Bovea & Pérez-Belis, 2012; Tomohiko Sakao, 2007; Shin et al., 2011; Turner, 2009; Vinodh & Rathod, 2010). Industrial approach to sustainable design is limited to factors like product recyclability and end of life design strategy (Xing et al., 2003); Resource constraints and life cycle aspects of product (Shin et al., 2011); environmental requirements (Bovea & Pérez-Belis, 2012) etc. Among the tools and methods used for sustainable design life cycle analysis with a variation of QFD was found to be very popular (Tomohiko Sakao, 2007; Turner, 2009; Vinodh & Rathod, 2010).

Limited literature has been found which attempted to consider the social aspect of sustainability as a part of sustainable design activity. For examples, few research papers included corporate social responsibility (CSR) and social impact as constituents of sustainability (S. A. Waage, 2007; S. Waage et al., 2005). Gagnon et al. (2012) were among the few researchers who attempted to explore sustainability in a comparatively comprehensive way and tried developing a sustainable engineering design process. However, his process of sustainable design is for industry context and is of limited use for practicing designers especially the novice ones. Moreover, it has limited inputs for creative designers.

The following section attempts to review sustainability philosophy integration within the context of design education, especially at the creative design phase.

### 2.5.2. Sustainable Design in Education

Design education in the last decade has responded to the consensus of integrating sustainability philosophy with design practice. Vanasupa and Burton (2010) pointed out that in the current context, choosing to design with or without sustainability consideration is no longer an option. Design professionals are bound to consider sustainability as an integral part of their design and design profession (Vanasupa & Burton, 2010). In recent years several attempts have been made to integrate the concepts of sustainability, sustainable development and sustainable design into education (Evangelinos, Jones, &

Panoriou, 2009; Filho, Manolas, & Pace, 2009; H. Middleton, 2009; Mulder, Segalas-Coral, & Ferrer-Balas, 2010). However, most of these attempts were focused on technical, and engineering education and very few attempts were focussed on creative design education.

In general sustainability is approached as an emerging science (Clark & Dickson, 2003) but design education view it as a constraint (ABET, 2008). In an empirical study conducted by Collado-Ruiz & Ostad-Ahmad-Ghorabi (2010), it was found that the availability of environmental information has an impact on the creative output of designers. The study reflected that detailed environmental information provided to the subjects reduced their creative output. However, the soft information did not produce this effect, and it was suggested that the future tools for sustainable design should be developed keeping this in mind.

The main motive of sustainability in design education should be focussed on developing a comprehensive and practical understanding of the philosophy which may enable them to use it in practice. Evangelinos et al. (2009) suggested the greening of curriculum, diffusion of knowledge on meaning and importance of sustainability, environmental management practices with Institute, etc. as few of the methods of sustainability education. He also suggested that the perception and attitudes of students are an important aspect of the process.

Pappas, Pierrakos, & Nagel (2012) suggested the use of Bloom's Taxonomy for teaching sustainability. Vanasupa & Burton (2010) deduced that there is a fundamental flaw in the way we are imparting sustainability education that is leading students to develop a flawed and incomplete mental model of sustainability. This flawed and incomplete mental model is leading to design decisions that are either flawed or incomplete. He suggested that the issue of sustainability integration was a consequence of our historically flawed mental models.

Mann, Walther, & Radcliffe (2005) raises the questions that design educators are not sure what students need to know and how to enable this learning. They highlight that the difference in understanding of what sustainable design poses a serious obstacle in imparting sustainability education. They argued that at first we need to develop a clearer picture of the sustainable design, what is it, how it is experienced and how it can be operationalized (Mann et al., 2005).

From the literature review presented above it can be observed that the integration of sustainability philosophy with design education requires a comprehensive and practical understanding of sustainable design along with an operational method of applying it in practice. Literature also emphasised on building the right perception, attitude and mental model towards sustainability and sustainable design. It was observed that creative design phase has not been explored much as a potential phase of sustainability integration.

In the background of literature reviewed this thesis at first attempts to develop a comprehensive understanding of sustainable design from a creative design perspective. It then attempts to integrate this understanding into the creative phase of designing a morphological approach. Such an approach is expected to inculcate the right mental model and promote sustainable development.

## 2.6. Revisiting the Research Gaps in Creative Design for Sustainability

Section 2.2.1 (page 26), reflected that the use of morphology is very crucial for creative designers especially novice ones and is a very efficient method of imparting design education. Section 2.2.2 (page 28) highlighted the importance of creative design phase in design morphology and its potential in managing complexity. It also indicated that this phase of designing can play a crucial role in sustainable design. Section 2.5 (page 43) elaborated on the existing approaches for integration of sustainability with the practice of designing in the industry (page 43) and design education context (page 44). It reflected that most of these approaches attempted to integrate sustainability into the process of designing. The presented research work also adopts this approach but is focussed on the creative phase of design, unlike the approaches discussed above.

It has already been elaborated that sustainability issues in practice are generally not considered a part of creative design phase (Lin et al., 2009; Sherwin, 2004). Most of the approaches towards integrating sustainability in design (Gagnon et al., 2012; T Sakao, 2007; Xing et al., 2003) is focussed on the later stages of the design morphology and not much work is done for the initial phase of design. The initial phase of design (creative design) owing to various attributes (already discussed in section 1.2.3, page 6; Section 1.2.4, page 10) holds great potential towards ensuring sustainable design (Lin et al., 2009; Sherwin, 2004). Despite this in normal practice creative designers treat sustainability parameters either optional or as an added set of constraints limiting the design space (S. Waage et al., 2005) (Collado-Ruiz & Ostad-Ahmad-Ghorabi, 2010). Even when

exclusively asked to consider sustainability, their approach is often found to be limited to environmental concerns only and does not cover the issue comprehensively (Lindley, 2010) (Kjøllesdal et al., 2012). This indicates that there is a lack of understanding and integration of sustainable design philosophy with creative design practice.

Moreover, a limited amount of research has been published which explores the role of creative design in incorporating sustainable design philosophy, especially at practice levels. The presented research addresses this research gap and attempts to explore the role of creative design in establishing sustainability and how best it can be integrated with the practice of creative design. This is the main concern of the presented research work and attempts to address the following research gaps:

### 2.6.1. Role of Sustainable Design Framework

The first research gap addressed in this thesis is towards developing a better and comprehensive understanding of the sustainable design philosophy from a creative design perspective. In literature, the philosophy evolved as a result of broadening of scope from earlier environmental conscious concepts like green design, eco-design, etc. and closely corresponds with the philosophy of sustainable development (Knight, 2009). By definition sustainable development is considered vague and interpretative by many researchers (Holden & Linnerud, 2007; Kjøllesdal et al., 2012; N. Middleton et al., 1993; Wackernagel & Rees, 1996). Consequently the understanding of sustainable design is also interpretative, depending upon the area of application and field of study (Coley & Lemon, 2009). This is evident from the varied understanding and interpretations of sustainable design available in literature (Coley & Lemon, 2009) often communicated through various frameworks and conceptual models (Ho & Ulanowicz, 2005; Todorov & Marinova, 2011). This often creates confusion for creative designers in deciding what sustainability variables should be considered during the creative phase of the design process.

Moreover, the existing models and frameworks of sustainable design are either domain based or principle based and finds limited use in the practice of creative design (Dusch et al., 2010). These models fail in pointing out the sustainability variables comprehensively and the type of inter-relation and contradiction between them (S. Waage et al., 2005). This may lead to a partial or wrong interpretation and conception of the knowledge leading to biased and limited actions (Frisk & Larson, 2011). Thus, a knowledge gap exists in understanding the philosophy of sustainable design from a

creative designers' perspective. There is a need for an improved framework model of sustainable design comprehensively highlighting upon sustainability variables that need to be considered at the creative design phase and the inter-relations between them.

### 2.6.2. Role of Mental Model and Problem Solving Approaches for Sustainable Design

The second research gap addressed in this thesis is towards the integration of sustainable design philosophy with the practice of creative design. One of the prominent approaches advocated by many researchers towards this is through integration of the philosophy with design education training (Boks & Diehl, 2006; Kjøllesdal et al., 2012; Vanasupa et al., 2010). However, according to Lindley (2010), many design educators are yet to embrace the multidimensional nature of sustainable design. In general the knowledge of sustainability usually stops at eco-design, material usage, carbon emission etc. rather than considering it holistically. In this context Vanasupa et al. (2010) states that the mental model imparted during design education and training is very critical towards building the foundation of sustainable design (Vanasupa et al., 2010). He points out that a flawed and partial mental model will lead to actions that are partial and biased. For example, Anders Kjøllesdal (2012) states that designers whose understanding of sustainability is limited to the issues of green design or eco-design, may well find themselves guilty of “greenwashing” (Kjøllesdal et al., 2012). However, in design literature there is a lack of studies towards understanding the existing perception and mental model of novice creative designers about the concept of sustainability and sustainable design (Kjøllesdal et al., 2012; Lindley, 2010).

As pointed out in the previous research gap, the understanding of sustainability and sustainable design faces with ambiguity and the existing framework and models of sustainability finds limited use in practice. With this background, limited studies have been conducted towards understanding how at present creative designers approach sustainability. Literature suggests that sustainability should be an integral part of designing, and there should not be any distinction between design and design for sustainability (Kjøllesdal et al., 2012). Despite this several researches believe that this has not yet happened in practice (Lin et al., 2009; Sherwin, 2004). This raises doubts about the existing perception and mental model of novice creative designers imparted during design education and design training.

Vanasupa and Burton (2010) posited that the mental model of reality which we consciously or unconsciously carry, reflects a lot of our actions, and deduces that it can point out the flaws in design education and training methodology (Vanasupa et al., 2010). Design as a cognitive activity has been extensively studied through empirical studies and is reported in the literature (Howard et al., 2008; Taylor et al., 2012). However, limited empirical studies have been conducted towards understanding the perception and mental model of creative designers regarding the concept of sustainability and sustainable design (Gagnon et al., 2012; Vanasupa et al., 2010). Moreover, it is not known how a creative designer at present approaches a sustainable design problem in practice, with their existing perception and mental model. Such a study in the pretext of existing literature and design training is expected to provide valuable information regarding the gaps in mental model of novice designers and the approaches (design morphology) adopted by them towards solving sustainable design problem in practice. This study is expected to indicate the gaps in imparting sustainable design education.

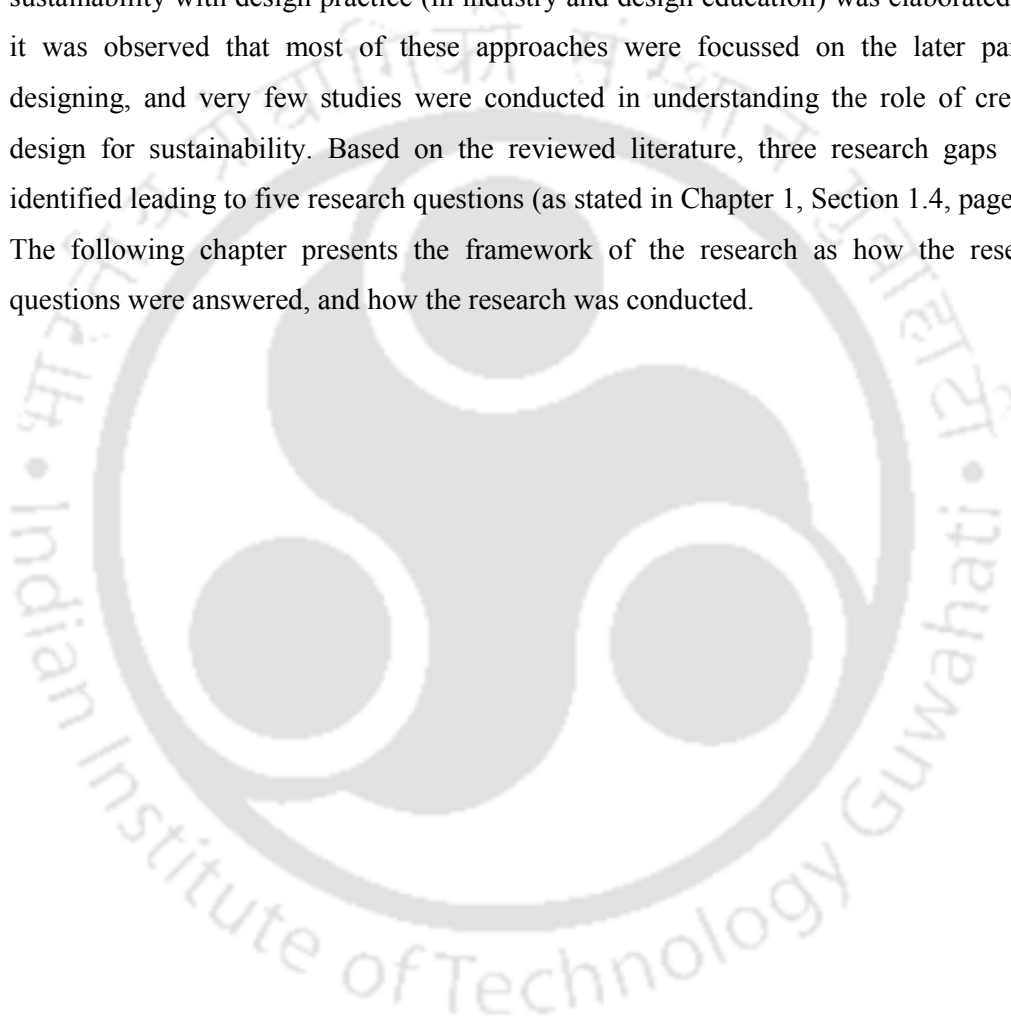
### 2.6.3. Role of Morphology for Sustainable Design

The third research gap addressed in this thesis is focussed on developing design morphology for training novice creative designers facilitating the integration of sustainable design philosophy with creative design practice. Design morphology in general concerns defining “how” and “when” things happen and in what desired order. It is considered to be very effective for training novice designers, and over a period it has become a very popular method for training and practicing designers (Howard et al., 2008). Traditionally designers were trained for designing products that satisfy human needs and aspiration, and different design morphologies were developed to support this. However, when it comes to sustainable design philosophy, the traditional design morphology popular in literature is often found to be of limited use, especially at the creative design stage.

The recently developed methods, tools and principles to support sustainable design activities are often found to be limited to the later stages of the design process (Lewis & Gertsakis, 2001), and there is a lack of clear operational method of approaching sustainability at creative design stage (Azkarate et al., 2011; S. Waage et al., 2005). Thus, there is a need for some support system that may complement designers at the creative design stage and prevents them from treating sustainability as an additional norm to be fulfilled or checked after designing is completed.

## 2.7. Conclusion

This chapter at first reviewed the literature concerning the practice of design (and its morphology) and the importance of creative design within design morphology. It then reviewed the philosophy of sustainability, its evolution in design and the various perspectives and definitions of its dimensions. The existing approaches to integration sustainability with design practice (in industry and design education) was elaborated, and it was observed that most of these approaches were focussed on the later part of designing, and very few studies were conducted in understanding the role of creative design for sustainability. Based on the reviewed literature, three research gaps were identified leading to five research questions (as stated in Chapter 1, Section 1.4, page 16). The following chapter presents the framework of the research as how the research questions were answered, and how the research was conducted.



## Chapter 3

### Framework of Research

This chapter presents the overall methodology used to address the research questions. At first, it describes the researcher's position about the scientific paradigm (ontological, epistemological and methodological position), and then presents in detail the research strategy (associated methods, instruments) used. The chapter also provides an overview of the methodological framework followed, highlighting the justification and description of methods used in the study

### 3.1. Introduction

Integrating the sustainable design philosophy with design practice is an urgent need towards achieving the goal of sustainable development. However, literature review presented in Chapter 2 revealed three major research gaps in this process of integration. The first gap is the lack of understanding of the sustainable design philosophy at practice level (section 1.3.1, page 13). The second gap is the lack of understanding about the existing mental model and problem-solving approaches of creative designers towards sustainability and sustainable design (section 1.3.2, page 14). The third gap is the lack of an integrated morphology for sustainable design (section 1.3.3, page 15).

This chapter illustrates the methodology followed in conducting this research along with research strategy, associated methods, and instruments used (in section 3.3). Before that following section presents the researcher's position about the scientific paradigm (ontological, epistemological and methodological position) adopted for this research.

### 3.2. Research Paradigm Adopted

Research paradigm, in general, is understood as a framework of perception, understanding and belief within which one's world or reality is interpreted (Shrestha, 2009). Bassey (1990) defined it as *"a network of coherent ideas about the nature of the world and the functions of researchers which, adhered to by a group of researchers, conditions their thinking, and underpins their research actions"* (Bassey, 1990). This is crucial as it determines the development and execution of the research. It also affects how the research findings will be analysed (Guba & Lincoln, 1998). Figure 3.1 shows the main components of research paradigm.

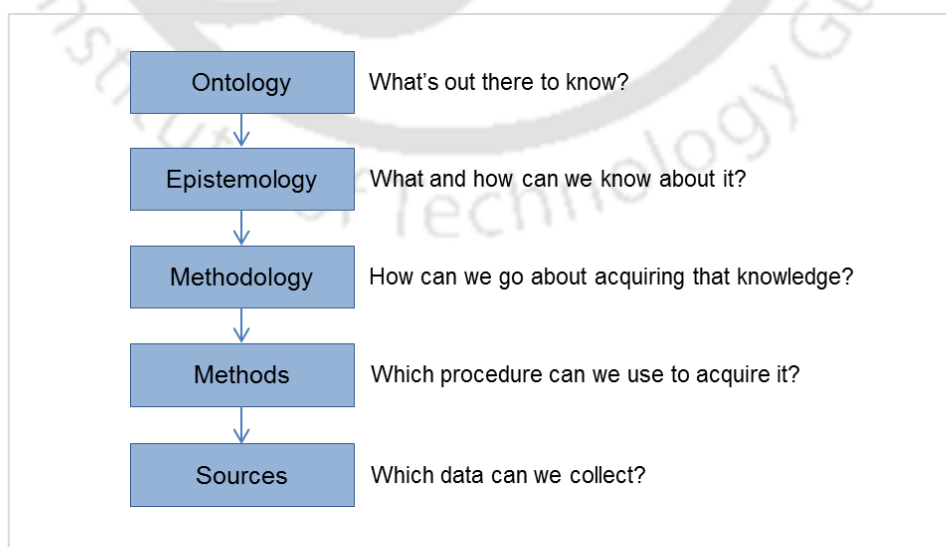
#### 3.2.1. Ontological Position

Ontology is concerned with the nature of reality – the kind of things that exist, the conditions of their existence and the relationships between these things. Generally a researcher either considers that there is a reality that is independent of his/her knowledge (realists' position) or considers that he/she participates in the construction of reality (relativists' position). The presented research positions itself in "constructivist realism".

Constructivism is a theory of knowledge that argues that humans generate knowledge based on observation and scientific study. It argues that people construct their understanding and knowledge of the world by experiencing things and reflecting on those experiences. When we encounter something new, we have to reconcile it with our previous ideas and experience, maybe changing what we believe, or maybe discarding the new information as irrelevant. In any case, we are the active creators of our knowledge. It has influenced many disciplines, including psychology, sociology, education and the history of science.

In the presented research we acknowledge that there is a reality outside the researcher's mind (realists' position) but, it can only be apprehended only to some extent. Therefore, the reality can be studied to some extent, and the acquired knowledge is incomplete, imperfect and generalisations are with some degree of probability. Researchers to understand reality develop different concepts, models and mental construction of the realities and worlds, but it is always a human construction, and can vary from the actual reality (Crotty, 1998).

This position is in contrast with the relativism that considers that there is no absolute truth or validity, the knowledge is relative and has subjective value according to differences in perception and consideration of the researcher. Although, to a certain extent the philosophy of sustainability and sustainable design have ambiguity in understanding that largely depends on the individual's perception, this research does not consider it to be purely hypothetical.



**Figure 3-1: Building blocks of research paradigm and their interrelation**  
Source: Adapted from (Shrestha, 2009)

### 3.2.2. Epistemology Position

The epistemological position is mainly concerned with the theory of knowledge regarding methods, validation and the possible ways of gaining it (Shrestha, 2009). It positions the researcher in relation to the reality and whether he/she can know about the reality objectively or subjectively. The presented research takes a constructivist epistemological position.

From the research questions (as stated in section 1.3, page 12), it can be observed that the presented research is centred on exploring the mental models of sustainability and sustainable design as existent in the mental realms of creative designers. Such kind of knowledge is largely qualitative in nature, and there is a lack of valid methodology (i.e. quantitative research). In such situations, observation of the phenomenon (experiences of the creative designer during designing) is the only option left in order to construct the mental model of creative designers about sustainability and sustainable design. The author thus acknowledges that the knowledge acquired in this context will be incomplete, imperfect and generalisation of reality that depends on researcher's construction of the mind.

The following section presents the methodological position based on the constructivist ontological and epistemological positions.

### 3.2.3. Methodological Position

Methodological position represents the general principles that underlie the process of investigating the reality, and how the generated knowledge is valid (Shrestha, 2009). It is concerned with the process of acquiring the knowledge. As discussed in Section 3.2.1 and Section 3.2.2, this research adopts a constructivist approach towards knowledge generation. This approach dictates the methodologies adopted for this research which is largely dominated by qualitative methods.

The presented research builds upon the assumption that integration of sustainability philosophy with the practice of creative design is a promising way of contributing to sustainable development. Following this, a three phase methodological approach for achieving the five objectives discussed in Section 1.4.1 (page 16) was adopted and is shown in Figure 3.2.

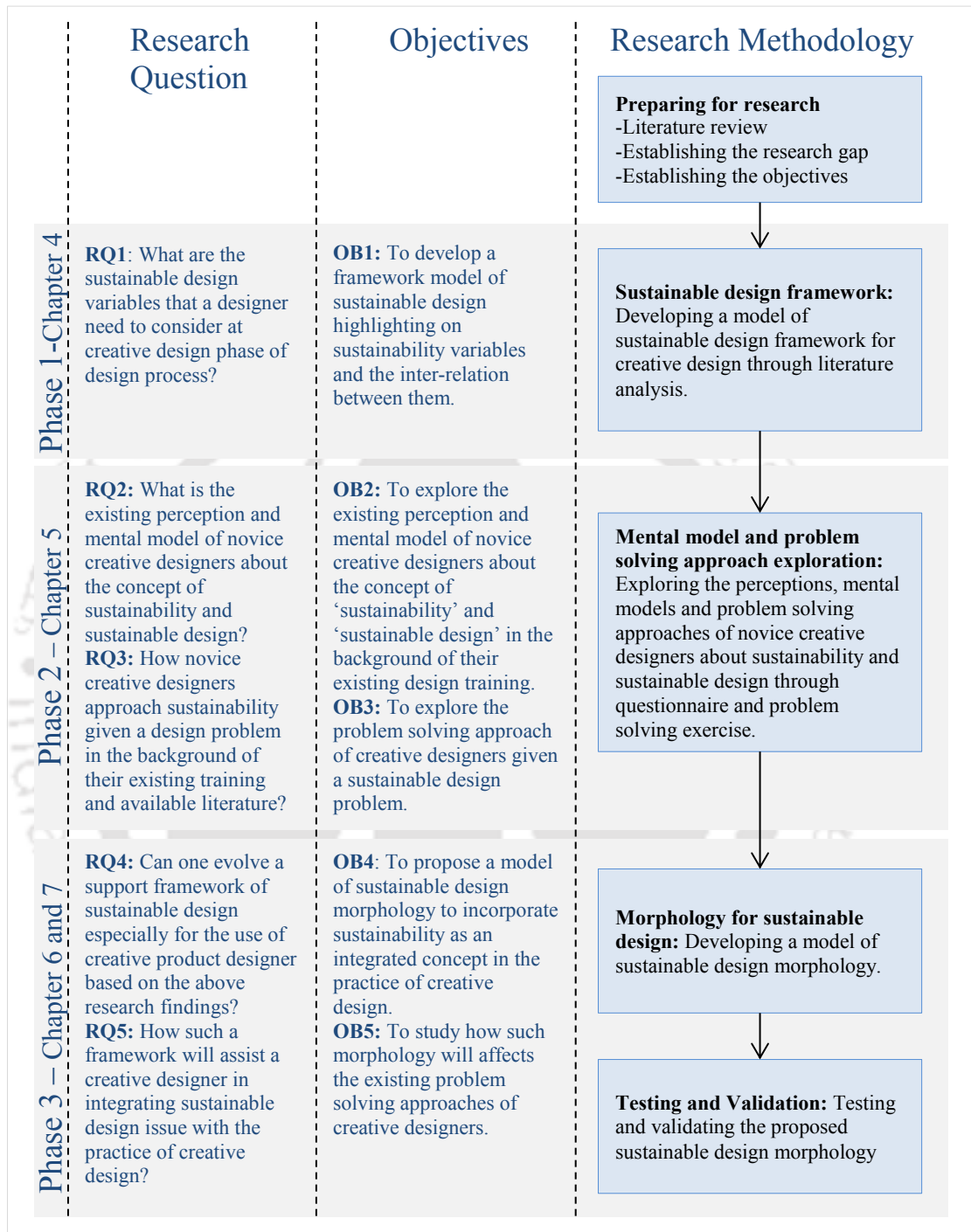


Figure 3-2: Three phase methodology adopted for conducting this research

Source: Author-generated

*The first phase* of the study was concerned with deriving a comprehensive framework for sustainable design covering the environmental, social and economic dimensions. It also attempted to highlight the contradicting nature of dimensions. This

phase attempts to answer RQ1 by achieving OB1. The research starts with developing an understanding of sustainable design philosophy from a creative design perspective (refer OB1, as illustrated in Section 1.4.2, page 16). This was executed through content analysis of the related definitions and understanding of sustainability available in the literature. This inference was carried out by the researcher's understanding of those definitions, which can be limited. The bias was avoided by considering multiple definitions from various authors have been considered and were validated through dry run testing. Despite this, there may be certain aspects of the definition that the author might have missed.

*The second phase* of the study attempts to capture the perception, mental model and problem solving approaches of creative designers about the concept of sustainability and sustainable design (refer OB2 and OB3, as illustrated in Section 1.4.2, page 16). The instrument used to capture this was a questionnaire and a problem-solving exercise. This instrument poses a series of limitation owing to which capturing the absolute picture is difficult. The author thus acknowledges that the models and mental constructs created, is a limited and simplified version of reality, and represents one of the possible ways of explaining the studied phenomenon. Further, it acknowledges that this construction was influenced by the experience and prior knowledge of the author.

*The third phase* of the study proposed a model of sustainable design morphology for creative design based on the observations and inferences from the previous two phases and then validated it through a dry run (testing) and empirical study. This phase attended RQ4 and RQ5 and attempted to achieve OB4 and OB5 (refer Section 1.4.2, page 16). It takes a critical theory position and attempts to understand how the proposed sustainable design morphology is likely to affect the mental perception and approaches of creative designers towards sustainable design while being introduced to the knowledge base.

Building on the above discussed ontological, epistemological and methodological position, the next section illustrates the research approach and strategy adopted in this thesis along with related methods and instruments used.

### 3.3. Overall Framework of Research - Approach and Strategy

This section illustrates the approach and flow of the study as shown in figure 3.3. The section also elaborates on the framework, method and instrument used for the research. The following section covers this phase wise.

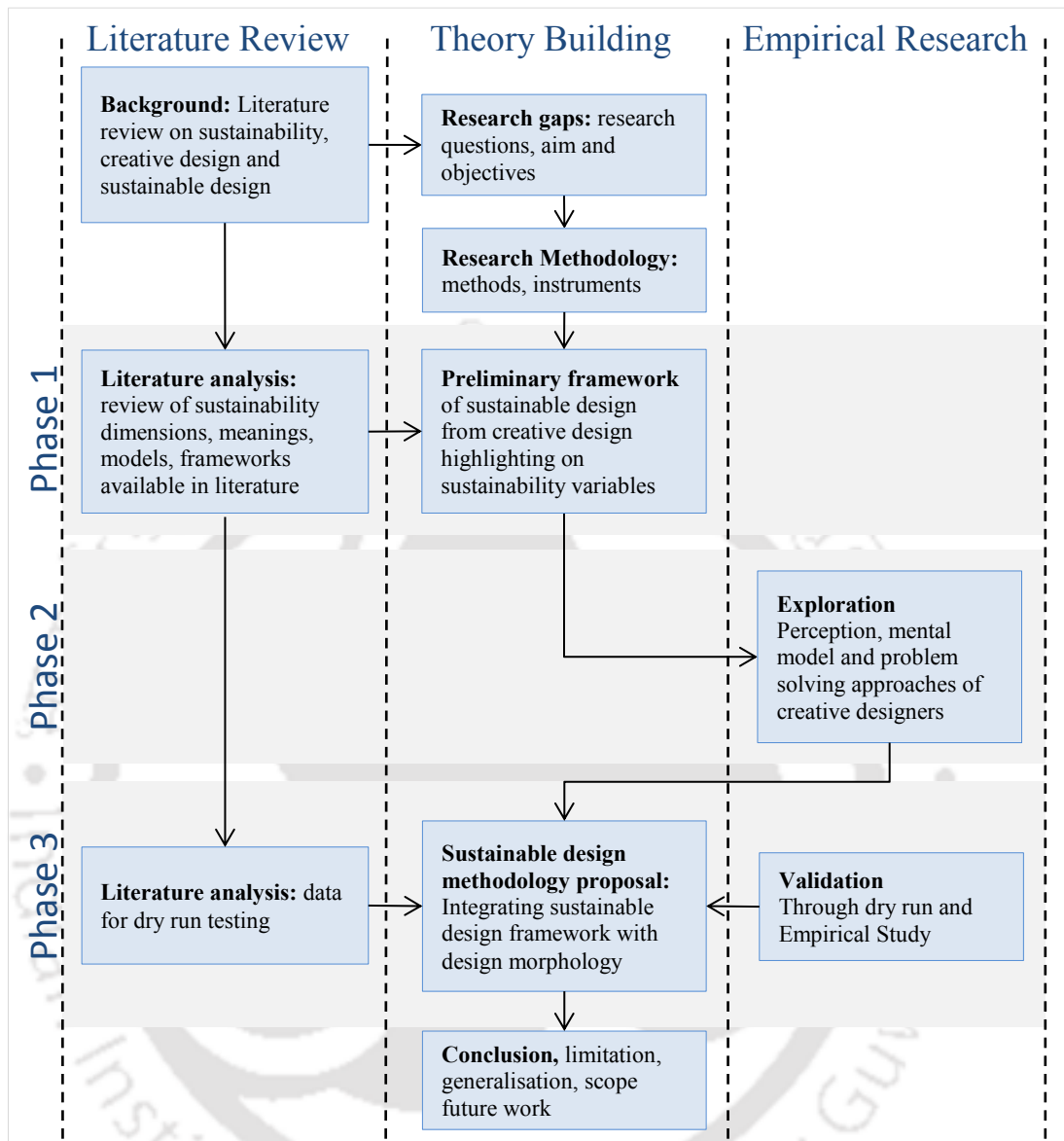


Figure 3-3: Overall flow of research broken into strategy

Source: Author-generated

### 3.3.1. Phase 1: Framework of Sustainable Design

The first phase of the study concerning RQ1 and OB1 (page 16) was focussed on exploring the understanding of sustainable design philosophy and is reported in Chapter 4. The objective was to develop a comprehensive framework model of sustainable design for creative designers. This phase employed the content analysis of the existing definitions and understanding of sustainability (along with its dimensions) available in the literature as a method of study. Based on it, a preliminary framework for sustainable design was derived. Figure 3.4 illustrates the process. The possible interaction between the different directions of sustainability was explored and was presented in the form of a

sustainability direction matrix. The framework is expected to be helpful for creative designers in exploring and identifying the sustainability variables and its implication on design.

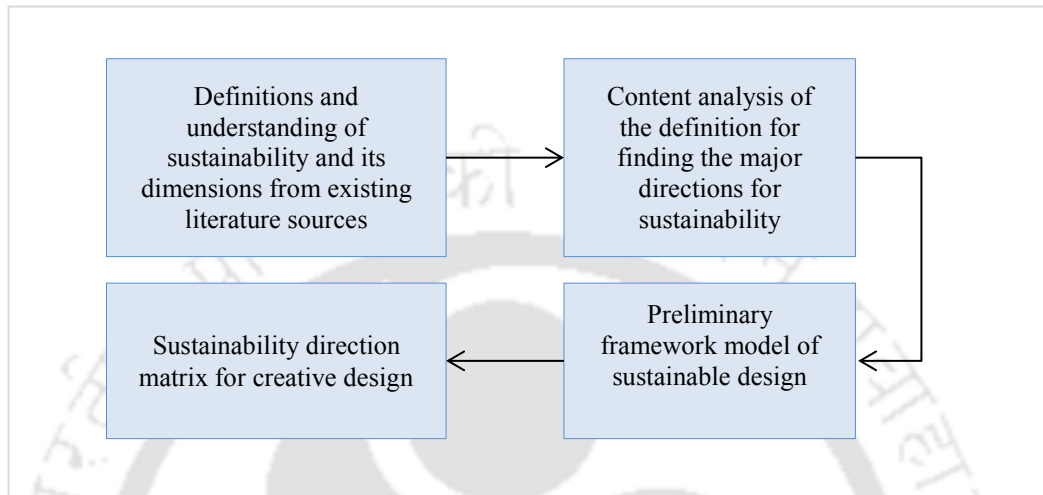


Figure 3-4: The process of deriving preliminary sustainable design framework for creative design

Source: Author-generated

Observing this from a constructivist position, the author argues that before starting the next phase of the study it is better to build a consolidated view of the existing observations and experiences of researchers. This will help in creating a point of reference comparing where are the gaps in mental models and existing approaches of creative designers towards sustainability.

### 3.3.2. Phase 2: Exploration of Mental Model and Problem Solving Approaches

As elaborated in section 1.3.2 (page 14), research gap exists towards exploring and understanding the mental models and problem-solving approaches of creative designers in the context of sustainable design. This phase of the study is focussed on this research gap and attempts to answer RQ2, RQ3 (page 16) and is reported in Chapter 5.

Mental models are internal symbol or representation of external reality, hypothesized to play a major role in cognition, reasoning and decision-making. Vanasupa et al. (2010) argue that since most of our actions and decisions are guided by the mental model of reality that we consciously or unconsciously carry; a flawed or a partial mental model of sustainable design among creative designers will result in decisions and actions that are biased and partial.

Creative design as an activity is cognitive in nature (Hubka and Eder 1996). In the past several studies were conducted to capture the mental model and cognitive behaviour of creative designers (both novice and expert) (Atman, Cardella, Turns, & Adams, 2005; Jiang & Yen, 2010; Stauffer & Ullman, 1988; Taylor, Coley, Houseman, & Roy, 2007; Yilmaz & Seifert, 2011). These studies revealed that the most appropriate time of capturing these cognitive processes is when a designer is designing.

Figure 3.5 shows the framework within which the study was carried out. A creative designer acquires the knowledge of sustainability and sustainable design either through design training or the exposure of popular literature on the subject. Based on his/her perception, understanding and point of view he/she builds his/her perception and mental model of the concept. A creative designer makes use of this mental model in problem solving and is reflected in his/her actions.

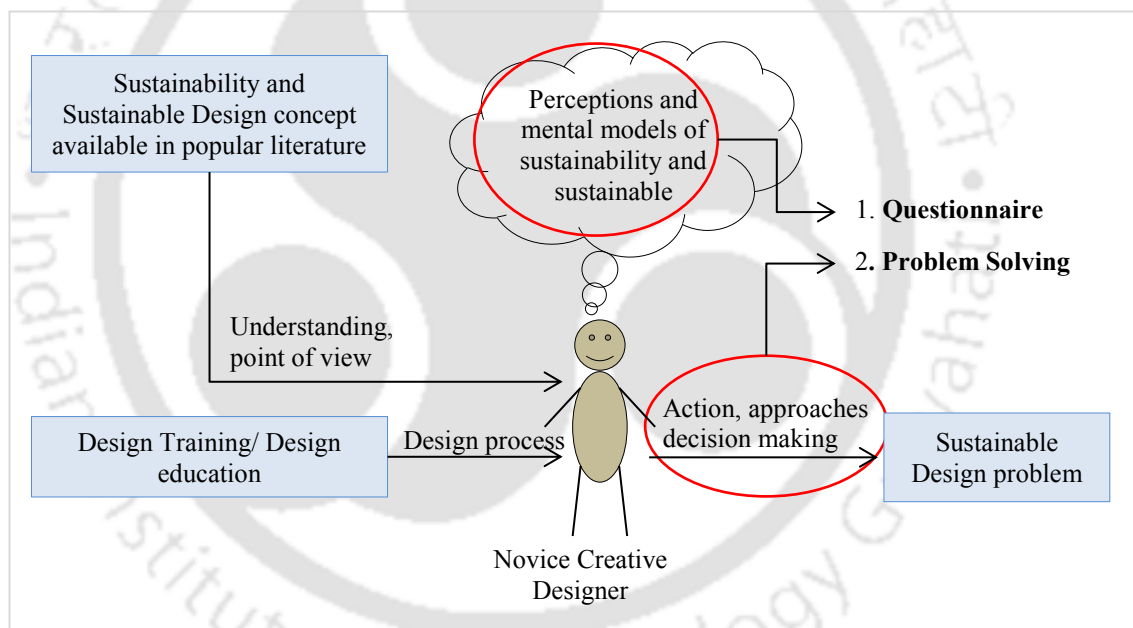


Figure 3-5: Framework for exploring mental model and problem-solving approaches

Source: Author-generated based similar study reported in literature

To capture the mental model and problem-solving approaches, an empirical study was conducted which employed an instrument specially designed for the purpose consisting of a questionnaire and a sustainable design problem. The study was conducted for achieving OB1 and OB2.

The method used for achieving OB2 was questionnaire (marked '1' in figure 3.5), designed especially for the purpose. The detail on the questionnaire is discussed in Section 5.2.3.1 (page 87) of chapter 5.

For OB3, the most appropriate time for capturing the cognitive behaviour was when a designer is designing. That is why a problem-solving exercise (marked ‘2’ in figure 3.5) was designed for the purpose and is discussed elaborately in section 5.2.3.2 (page 88) of chapter 5.

### 3.3.3. Phase 3: Proposal and Validation of Sustainable Design Morphology

This part of the study was attributed to developing a model of sustainable design morphology based on the gaps in understanding which has been found in the phase 2 and the framework model of sustainable design proposed in the phase 1 (reported in Chapter 6 and 7). In this phase at first the comprehensive framework of sustainable design was integrated with the creative phase of traditional design morphology. It was then validated through a dry run (test) and empirical study. Figure 3.6 illustrates the process of developing the proposed morphology of sustainable design for the creative design.

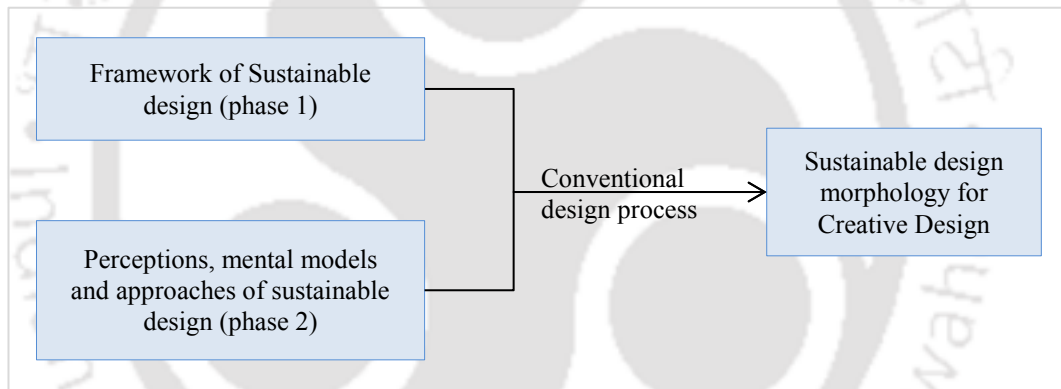


Figure 3-6: Schema of sustainable design method development for creative design  
Source: Author-generated

## 3.4. Conclusion

This chapter at first presented the researcher’s position in relation to the scientific paradigm (ontological, epistemological and methodological position). Then it elaborated on the overall framework of research that was conducted in three phases. It also discussed the research strategy adopted, and the framework within which the three phases were conducted. The following chapter presents the first phase of the study and delineates on the development of the preliminary framework model for sustainable design.



## Chapter 4

(Phase - 1)

### Developing a Framework for Sustainable Design

This chapter reports phase 1 of the study focused on RQ1 (page 15), and attempts to achieve OB1 (page 16). This phase derived a comprehensive framework for sustainable design based on the content analysis of literature, which presented contesting definitions of sustainable design and its dimensions.

## 4.1. Introduction

Frameworks are the logical structures that make any concept (or philosophy) understandable, especially to novice and non-experts. This chapter intends to develop a comprehensive framework for sustainable design.

The research gap identified in section 1.3.1 (page 12) and 2.6.1 (page 47) indicates that a knowledge gap exists towards developing a comprehensive understanding of sustainable design. Reviewed literature presented in Chapter 2 illustrated varied understating and interpretations of sustainable design. Moreover, its historical roots in environmental-conscious concepts of green design and eco-design lead to a partial understating of the philosophy biased towards environmental dimension. Therefore, most often its practical implication was found to be limited to material considerations, eco-design principles, meeting government regulations etc., and does not cover the issues comprehensively (Kjøllestadal et al., 2012; Lindley, 2010).

At present, available models of sustainable development are used as a basis for understanding and implementing sustainable design in practice (Ho & Ulanowicz, 2005; Todorov & Marinova, 2011). Most of these models and frameworks are either domain based or principle based (Dusch et al., 2010; Todorov & Marinova, 2011) and finds limited use in practicing creative design, especially for novice designers. Developmental models are different from designing models. In practice, these models fail in pointing out the sustainability variables comprehensively so essential within the designing morphology. Although, these models point out that there is a relationship between various dimensions of sustainability but is found to be of limited use in pointing out the type of inter-relationship and the contradictions between them (S. Waage et al., 2005). In the absence of a suitable framework, in practice the understating and exploration of sustainability affecting factors becomes ad-hoc. This is expected to lead a designer to the partial or wrong interpretation of the knowledge (sustainable design) resulting in biased and limited decision making (Frisk & Larson, 2011).

Thus, there is a need for a comprehensive operative framework for sustainable design that can guide creative designers in practice. This chapter covers RQ1 and OB1, which is restated below for the convenience of reading.

**RQ1:** What are the sustainable design variables that a designer needs to consider at the creative design phase of designing process?

**OB1:** To develop a framework model of sustainable design highlighting on sustainability variables and the inter-relation between them.

## 4.2. Material and Methods

Content analysis of the existing definitions and understanding of sustainability (along with its dimensions) available in the literature (see Chapter 3, Section 3.3.1, page 57) was employed for developing the framework. At first the definitions and understanding of sustainability along with dimensions were tabulated and then major directions for sustainability were derived from it.

Based on the directions for sustainability a preliminary framework for sustainability was proposed. This framework was then used to highlight the contradicting nature of different dimensions in a matrix form. The framework is expected to elucidate the dimensions of sustainability and their inter-relation and assist creative designers in reflecting on the implication of its dimensions in design decision making.

## 4.3. Development of a preliminary framework for Sustainable Design

The evolution of sustainable design philosophy with time from earlier environmental conscious concepts like green design, eco-design etc., and the addition of socio-economic dimension due to close correspondence with sustainable development philosophy has been summarised in Figure 4.1 (discussed elaborately in section 2.4, page 34). This figure presents a comprehensive understanding of sustainable design in relation to the environmental-conscious philosophies of green design and eco-design.

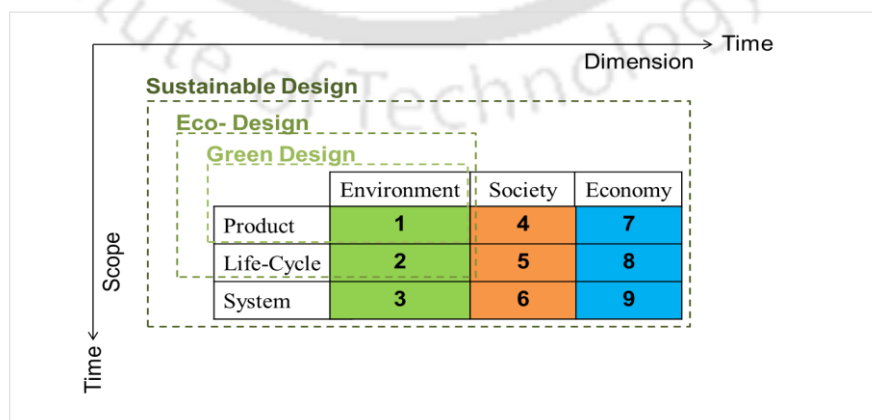
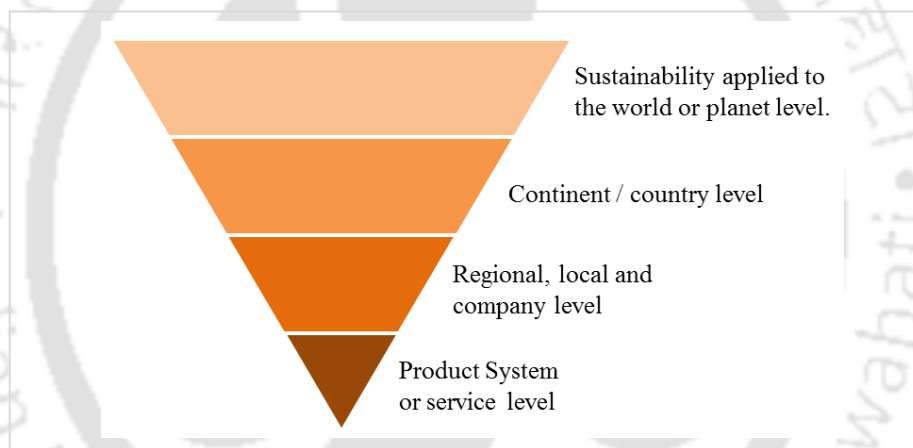


Figure 4-1: A comprehensive understanding of sustainable design  
Source: Author-generated based on literature review

It can be observed that the evolution of sustainable design philosophy has broadened in terms of scope (from product to lifecycle to the system) as well as dimensions (environment to society and economy). A comprehensive understanding of sustainable design philosophy should encompass all the interaction cells (1 to 9) shown in Figure 4.1. The understanding of these interacting cells varies depending upon the field of study & context of the application. Literature produces several definitions and understanding of sustainability and sustainable design from various perspectives applicable at various levels (Azkarate et al., 2011). Figure 4.2 shows an example of various levels at which sustainability can be applied. However, most of the definitions and understanding of sustainability and sustainable design (along with its dimensions) reflected across literature are from the top level perspective like planet level, country level etc. and finds limited in practice of creative design.



**Figure 4-2: Levels at which sustainability can be applied**  
Source: Adapted from (Azkarate et al., 2011)

The following section at first summarises the definitions and understating of sustainability and its dimensions available in the literature (elaborately discussed in section 2.4.1.1, page 36; 2.4.1.2, page 40 and 2.4.1.3, page 41). It then extracts major directions for sustainability based on the content of the summarised definitions and understanding.

#### 4.3.1. Environmental Sustainability

As discussed in Section 2.4.1.1 (page 36), the fundamental understanding of environmental sustainability is rooted in the human-environment relationship, popularly known as world views. The most accepted set of definitions and understanding is based on the anthropocentric or techno-centric world views. Environmental sustainability is

aimed at maintaining a certain quo in nature for the sustenance of resources that are essential to human development and survival (Dusch et al., 2010). It can be achieved through conservation of resources, maintenance of ecology and its systems and reducing the negative impact on the environment. Table 4.1 and 4-2 enlists the reviewed definitions and understanding of environmental sustainability available in the literature.

Table 4-1: Varied definition and understating of environmental sustainability (part-1)

Source: Author-generated based on reviewed literature

|                              | Source                 | Definitions/Understanding  | What it covers?   |
|------------------------------|------------------------|--|---|
| Environmental Sustainability | (Goodland, 1995)       | “seeks to improve human welfare by protecting the sources of raw materials used for human needs and ensuring that the sinks for human wastes are not exceeded, to prevent harm to humans.”   | Human welfare<br>Raw materials (resources)<br>Human waste (pollution)   |
|                              | (Holdren et al., 1995) | Maintenance and improvement of the integrity of the Earth’s life-supporting systems through preservation of biological diversity, and biogeochemical integrity of the biosphere through conservation and proper use of air, water and land resources   | Life supporting systems (air, water, land, food, etc.)<br>Biological diversity<br>Bio-geochemical integrity<br>Air, water & land resources  |
|                              | (OECD, 2001)           | Defines four strategic criteria for environment sustainability:<br><b>1. Regeneration-</b> Renewable resources to be used efficiently and their use should not exceed their long-term rates of natural regeneration.<br><b>2. Substitutability-</b> Non-renewable resources to be used efficiently limited to levels that can be offset by substitution with renewable resources.<br><b>3. Assimilation-</b> Releases of hazardous or polluting substances into the environment should not exceed their assimilative capacity.<br><b>4. Avoiding irreversibility.</b><br>And proposes the following objectives:<br><b>1. Maintaining the integrity</b> of ecosystems through the efficient management of natural resources<br><b>2. Decoupling</b> environmental pressures from economic growth<br><b>3. Improving information</b> for decision-making: measuring progress through indicators<br><b>4. Enhancing the quality of life:</b> the social and environmental interface: enhancing quality of life<br><b>5. Global environmental interdependence:</b> improving governance and co-operation | Renewable resource<br>Non-renewable resources<br>Hazardous and polluting substances<br>Irreversible effects<br>Natural resources<br>Integrity of ecosystem<br>Economic growth<br>Environmental pressure<br>Information for decision makers<br>Quality of life<br>Global environment |
|                              | (Sutton, 2004)         | the ability to maintain the qualities that are valued in the physical environment  | Valued physical environment (land, air, water, etc.)  |

Table 4-2: Varied definition and understating of environmental sustainability (part-2)

Source: Author-generated based on reviewed literature

|                              | Source  | Definitions/Understanding   | What it covers?   |
|------------------------------|---|---|---|
| Environmental Sustainability | (Millennium Ecosystem Assessment, 2005)         | Environmental Sustainability may be defined as maintaining nature's services at a suitable level. Four categories of ecosystem services are:<br><b>1. Provisioning</b> - food, fresh water, wood and fibre, fuel, etc.<br><b>2. Regulatory</b> - Climate regulation, flood regulation, disease regulation, water purification, etc.<br><b>3. Cultural</b> - Aesthetic, spiritual, educational, recreational, etc.<br><b>4. Supporting</b> - Nutrient cycling, soil formation, primary production, etc.  | Provisioning food, freshwater, clean air, etc.<br>Regulating climate, flood, disease, pure water, etc.<br>Maintaining cultural aspects (aesthetics, spiritual, etc.)<br>Supporting nutrient cycle, soil formation, etc. |
|                              | Moldan (2009) as cited in (Moldan et al., 2012) | Enlists basic principles of environmental sustainability:<br><b>1. Long-term perspective</b> (without any designated time limit);<br><b>2. Understanding of the non-linear evolution</b> of complex systems (tipping points, thresholds, sudden, unpredictable changes);<br><b>3. Taking feedbacks into account</b> (in particular the positive ones);<br><b>4. Regard for different scales</b> (in time and space);<br><b>5. Flexibility</b> (the ability to react to a changing situation, learning by doing);<br><b>6. Key importance of local conditions;</b> and<br><b>7. Respect for living nature</b> in general and for biological diversity in particular.   | Long-term perspective<br>Non-linear systems<br>Feedbacks<br>Scale of time and space<br>Flexibility<br>Local conditions<br>Bio-diversity   |
|                              | (Moldan et al., 2012)                           | Focus of six systems:<br><b>1. Climate systems</b> - covering climate and climate change, climate risk management, mitigation and adaptation.<br><b>2. Human settlements and habitats</b> - covering cities, urbanization and transport.<br><b>3. Energy systems</b> - covering energy use, energy conservation, renewable energy, energy efficiency and bioenergy.<br><b>4. Terrestrial systems</b> - covering natural and managed ecosystems, forestry, food systems, biodiversity and ecosystem services.<br><b>5. Carbon and nitrogen cycles</b> - covering sources and sinks, feedback processes and links to other systems.<br><b>6. Aquatic systems</b> - covering marine and freshwater ecosystems, fisheries, currents and biodiversity. | Climate systems<br>Human settlements and habitats<br>Energy systems<br>Terrestrial systems<br>Carbon and nitrogen cycle<br>Aquatic systems  |

It can be noted from the table 4-1 and 4-2 that most of the definitions and understanding of environmental sustainability comes from disciplines like environmental science, ecology, etc. and not from design. Moreover, it can be observed that there is a shift in focus of understanding of environmental sustainability towards the planetary levels and planetary systems. Creative designer find these definitions/understanding of limited use in practice, as it does not clearly give directions for decision making during designing. It can be unclear and confusing for them (especially for novice designers) to understand the implications of such definitions and understanding in design decision making.

From Table 4-1 and 4-2, a diverse range of definitions, approaches, understanding and interpretations can be observed. This diversity sometimes alludes in understanding the concept of environmental sustainability and the directions for achieving it. To impose some order on the concept for a comprehensible understanding, clustering was done to arrive at the following typology.

1. Sustaining Resources
2. Maintaining ecological systems
3. Regulating environmental impact
4. Developing environmental awareness

This typology presents four directions for environmental sustainability and is presented in Table 4-3. These directions are further elaborated in the following sections.

#### *4.3.1.1. Sustaining Resources*

The first direction for environmental sustainability is the sustenance of resources, particularly those resources that are useful and essential for development and survival of human beings. The resources provided by nature can be classified as renewable (air, water, land, forest, sunlight, etc.) and non-renewable (petroleum, minerals, coal, etc.). For sustenance of these resources, renewable resources should be used within the regeneration rate and non-renewable resources should be used efficiently. Strategies like reuse, refurbishing, remanufacturing, recycling, etc. can be adopted for closing the cycle of non-renewable resources. Another way of sustaining is by substituting it with appropriate renewable resources.

Table 4-3: Direction for environmental sustainability

Source: Author-generated

|                              | Directions                         | What it covers?   |
|------------------------------|------------------------------------|---|
| Environmental Sustainability | Sustaining Resources               | <ul style="list-style-type: none"> <li>- protecting the sources of raw materials used for human needs</li> <li>- use of renewable resources within regeneration rates</li> <li>- Efficient use of non-renewable resources, substitution with renewable resources.</li> <li>- efficient management of natural resources like air, water and land resources</li> <li>- maintaining the qualities that are valued in the physical environment.</li> <li>- Provisioning – food, fresh water, wood and fibres, fuel, etc.</li> <li>- Long term perspective for resource use.</li> <li>- Energy systems - covering energy use, energy conservation, renewable energy, energy efficiency and bioenergy.</li> <li>- Decoupling environmental pressure from economic growth</li> </ul>   |
|                              | Maintaining ecological systems     | <ul style="list-style-type: none"> <li>- avoid irreversible effects on natural systems</li> <li>- regulation of climate, flood, disease, water</li> <li>- Supporting nutrient cycling, soil formation, etc.</li> <li>- understanding the non-linear evolution of complex systems (tipping points, thresholds, sudden, unpredictable changes)</li> <li>- taking feedback into account.</li> <li>- key importance to local conditions</li> <li>- Preservation of biological diversity, bio-geochemical integrity.</li> <li>- respect for living nature in general</li> <li>- climate systems – climate change, climate risk management, mitigation and adaption</li> <li>- Human settlements and habitats - covering cities, urbanization and transport.</li> <li>- Terrestrial systems - covering natural and managed ecosystems, forestry, food systems, biodiversity and ecosystem services.</li> <li>- Carbon and nitrogen cycles - covering sources and sinks, feedback processes and links to other systems.</li> <li>- Aquatic systems - covering marine and freshwater ecosystems, fisheries, currents and biodiversity.</li> </ul> |
|                              | Regulating environmental impact    | <ul style="list-style-type: none"> <li>- Limiting human waste within nature's sink capacity</li> <li>- Release of hazardous and polluting substances within earth's assimilative capacity</li> <li>- Global environmental improvement through governance and co-operation.</li> </ul>   |
|                              | Developing environmental awareness | <ul style="list-style-type: none"> <li>- information for decision makers</li> <li>- Enhance the social and environmental interface-enhancing quality of life</li> <li>- Awareness through cultural, aesthetics, spiritual, educational means, etc.</li> </ul>   |

#### 4.3.1.2. *Maintaining ecological systems*

This direction of environmental sustainability aims towards maintenance of ecological systems like climate systems, aquatic systems, carbon-nitrogen cycles, biological diversity, etc. Although, most of the time these systems do not pose an immediate threat to human survival, in the long run, it can cause irreversible damage. These systems form a delicate balance of ecology and are essential for human survival.

#### 4.3.1.3. *Regulating environmental impact*

The third direction for environmental sustainability is regulation of negative environmental impact. The human activity of production and consumption produces various types of wastes, releases hazardous and polluting substances. These wastes and toxic substances are not only a threat to human beings but also affect ecological systems and environment. These negative environmental impacts should be reduced within the assimilative capacity of the Earth.

#### 4.3.1.4. *Developing environmental awareness*

Environmental awareness development is directed towards improving human behaviour for environmental sustainability. It is towards understanding the fragility of our environment and the importance of its protection. It aims at building environment-friendly behaviour, ethics and enhances the social and environmental interface. Information and knowledge should be provided to the decision makers regarding this so that they can take appropriate decisions for human development. It also includes cultural, aesthetics, spiritual, recreational factors.

| ↑ - complementary<br>↓ - conflicting<br>↔ - mutually complementary<br>↕ - contextual | Sustaining Resources | Maintaining ecological systems | Regulating environmental impact | Developing environmental awareness |
|--|----------------------|--------------------------------|---------------------------------|------------------------------------|
| Sustaining Resources   |                      |                                |                                 |                                    |
| Maintaining ecological systems   |                      |                                |                                 |                                    |
| Regulating environmental impact  | ↑                    | ↕                              |                                 |                                    |
| Developing environmental awareness   | ↑                    | ↑                              | ↑                               |                                    |

Figure 4-3: Interaction matrix of environmental sustainability direction

Source: Author-generated

#### 4.3.1.5. *Intra-dimensional relationship – Environment*

This section attempts to highlight on the type of relationship (like conflicting, complementing, etc.) between the different directions of sustainability. Here four types of possible relationships are defined. It should be noted that these relationships are generic, and context dependent. There is a possibility of another type of relationships also.

1. ↑ - complementary – row complements column
2. ↓ - conflicting - row and column conflicts
3. ↔ - mutually complementary – row and column complements each other
4. ↕ - contextual – depends on the context

**Regulating environmental impact vs. sustaining resources:** Regulating the environmental impact through strategies like material elimination, material reduction, material replacement, reusing and recycling complements the sustenance of those materials.

**Regulating environmental impact vs. maintaining ecological systems:** These two are mutually complementary directions as a reduction of environmental impacting factors will also help in maintaining ecological systems and vice versa.

**Developing environmental awareness vs. sustaining resources:** The development of environmental awareness among the stakeholders will motivate them to take steps for sustaining resources. For example water conservation campaigns, helps improving the behaviour of users and they take mitigating steps towards saving water.

**Developing environmental awareness vs. maintaining ecological systems:** Similar to the previous case, if the stakeholders are well informed about the ecological impact of their actions, there is a strong possibility that they will adopt mitigating steps.

**Developing environmental awareness vs. regulating environmental impact:** A well aware stakeholder is likely to take mitigating actions towards their environmental degrading behaviours.

#### 4.3.2. Social Sustainability

The prime focus of social sustainability is the development of the society (people) in the positive direction. It can only be achieved by fulfilling the basic and higher order needs of the society at present and of future. The literature on social sustainability is found to be varying in understanding depending upon the researchers, point of view and the area of application. Vallance et al. (2011) reviewed these varied understanding presented by

various authors and found three major directions. Their typology consists of the following directions.

1. Developmental Social Sustainability,
2. Bridge social sustainability, and
3. Maintenance social sustainability

The presented research work adopts this typology as directions for social sustainability. The typology is summarised in Table 4-4 and elaborated in following sections.

Table 4-4: Social sustainability  
Source: Adapted from (Vallance et al., 2011)

| Social Sustainability | Directions                          | What it covers?  |
|-----------------------|-------------------------------------|--|
|                       | Developmental Social Sustainability | <p>It focuses on the fulfilment and equal access to basic and higher order needs of humans (inclusive of people from diverse social-economic, age, sex, religious background).</p> <p><b>1. Tangible basic needs</b> of humans such as pure air, potable water, healthy food, housing, health and medication, basic infrastructure and services, energy, sanitation, etc.</p> <p><b>2. Intangible basic needs</b> such as equity in access to resources and power, freedom, education, employment, justice, access to influential decision making, etc.</p> <p><b>3. Higher order needs</b> such as building the social capital, social cohesion, removing social exclusion, general capital building, merging environmental and economic needs, conserving and enhancing resource base, sustainable level of population, reorienting technology and managing risks etc.</p> |
|                       | Bridge Social Sustainability        | <p>It focuses on building better bridges between people and a bio-physical environment promoting eco-friendly behaviour and stronger environmental ethics.</p> <p><b>1. Non transformative bridges</b> like adoption of new technological innovations, banning CFCs, provision of recycling facilities, creating awareness and providing information on how one can improve environment, etc.</p> <p><b>2. Transformative bridges</b> – challenges the fundamental ways in which the environment is socially constructed and re-imagining people’s relationship with the environment, other humans and non-humans.</p>   |
|                       | Maintenance Social sustainability   | <p>Focuses on maintaining the preferred way of living (tradition, culture, etc.).</p> <p>Maintenance of traditions, practices, preferences, places that people would like to be maintained (sustained) or improved, social and cultural preferences, the environment, characteristics, etc.</p>  |

#### 4.3.2.1. *Developmental Social Sustainability*

This direction of social sustainability is focussed on fulfilling the basic as well as higher order needs of everyone (inclusive of people from diverse social-economic, age, sex, religious background or living in developed, developing, under-developed nations). It consists of tangible basic needs like healthy food, potable water, housing, medication, energy etc. as well as intangible basic needs of equal access to resources, education, employment, decision-making, freedom and justice. These needs are more relevant for developing and under-developed countries. For developed countries the fulfilment of higher order needs such as building social capital, social cohesion, population management, removing social exclusion, etc. should be the focus.

#### 4.3.2.2. *Bridge Social Sustainability*

The focus of bridge social sustainability is on building a better connection between people and bio-physical environment for eco-friendly behaviour and stronger environmental ethics. The building of these connections or bridges can be incremental (non-transformative) like adoption of environmentally friendly technology, facilitating recycling, creating awareness, providing information, etc. or radical which challenges the fundamental ways in practice.

#### 4.3.2.3. *Maintenance Social Sustainability*

Preservation and maintenance of traditions, practices, preferences, preferred ways of living, etc. are the major concern of maintenance social sustainability. It includes preservation of social and cultural preferences that people want to be sustained.

#### 4.3.2.4. *Intra-Dimensional Relationship – Social Sustainability*

The three directions for social sustainability often overlaps or have conflicting interests that need to be understood for taking a conscious decision making. This section attempts to highlight the four types of relationship discussed in Section 4.3.1.5 (page 70) for social sustainability directions. Figure 4-4 illustrates the interaction matrix.

**Bridge vs. developmental social sustainability:** The success of efforts taken in the direction of building better bridges between people and their environment is very contextual. In under-developed and developing economies, there are a large number of people whose basic needs are not fulfilled. Expecting that such people will care for the environment beyond their needs is hypothetical. However, this direction will complements each other for places where the basic needs of people are fulfilled.

|  |                                     |                              |                                   |
|--|-------------------------------------|------------------------------|-----------------------------------|
| ↑ - complementary<br>↓ - conflicting<br>⇕ - mutually complementary<br>⇕ - contextual | Developmental social sustainability | Bridge social sustainability | Maintenance social sustainability |
| Developmental social sustainability  |                                     |                              |                                   |
| Bridge social sustainability   | ⇕                                   |                              |                                   |
| Maintenance social sustainability  | ↓                                   | ⇕                            |                                   |

Figure 4-4: Interaction matrix of social sustainability direction  
 Source: Author-generated based on work of (Vallance et al., 2011)

**Maintenance vs. developmental social sustainability:** There is a strong possibility that the maintenance of social, cultural, traditional preferences of people will conflict with developmental social sustainability. For example, people may prefer staying in large houses in cities but it may conflict with an equal share of spaces among all.

**Maintenance vs. bridge social sustainability:** Sometimes the maintenance of certain traditions and preferences complements the protection of the environment. For example, certain trees and groves are considered holy in Indian sub-continent and people will like it to be maintained. This preference complements the bridge social sustainability. However, there are other situations when it may contradict. For example preferences of big houses will need more land for which forests are cleared. Here both the directions contradict. As a result, these two directions have a contextual relationship.

### 4.3.3. Economic Sustainability

Economic Sustainability, in general, is defined as the ability of an economy to support a defined level of economic production indefinitely (thwink.org, 2014). It is aimed at promoting the use of resources in both efficient and responsible way such that it can sustain long-term benefits or profits without creating environmental concerns or impairing the balance of local ecology (wiseGEEK, 2014). Table 4-5 summarises the definitions and understanding of economic sustainability from various perspectives which has already been elaborated in Section 2.4.1.3 (page 41) of chapter 2.

Table 4-5: Economic sustainability

Source: Author-generated based on reviewed literature

|                         | Source                  | What is it?  | What it covers?   |
|-------------------------|-------------------------|--|---|
| Economic Sustainability | (wiseGEEK, 2014).       | Promote the use of resources in both efficient and responsible way such that it provides long-term benefits. Its objective is to make a profit without creating environmental concerns and harming the balance of local ecology. | <ul style="list-style-type: none"> <li>- A selection of environmentally friendly raw material.</li> <li>- Waste disposal strategy for least impact</li> <li>- promote community investment.</li> <li>- Viable operation for long time</li> <li>- Profitability over the long term.</li> <li>- Financial welfare for all the stakeholders (owner, employees, community).</li> </ul>  |
|                         | (World Bank, 2006)      | Sustenance of capital over a very long period  | <ul style="list-style-type: none"> <li>- <b>Man-made capital</b> is the wealth as in money or property, owned, or accumulated which is available for use in the production of more wealth. It also includes physical infrastructures, a physical manifestation of information, techniques, and knowledge required to produce goods and services.</li> <li>- <b>Natural capital</b> forms the basis for all human economic activities and includes land, air, water, living organism and all formations of the Earth's biosphere that has potential of providing us with ecosystem goods and services necessary for survival and wellbeing of human.</li> <li>- <b>Human capital</b> refers to the stock of competencies, knowledge, habits, social and personality attributes, including creativity, cognitive abilities, embodied in the ability to perform labour so as to produce economic value. It is often connected with to education, productivity, growth, and innovation (Michael, 2013).</li> <li>- <b>Social capital</b> refers to the attributes of the society that shape the quality and quantity of social interactions like relationship building, institutions, social cohesion, etc. These attributes are very important for economic sustainability.</li> </ul> |
|                         | (Moldan et al., 2012)   | Maintaining economic growth  |   |
|                         | (wiseGEEK, 2014)        | An economy that provides the monetary resources to support the community.  | <ul style="list-style-type: none"> <li>- Capital for community development</li> <li>- Renewable use of environmental resources.</li> </ul>  |
|                         | (Gilman & Robert, 1992) | Defines five reservoirs of wealth and a sustainable economy must maintain and increase this wealth   | <ul style="list-style-type: none"> <li>- environmental capital</li> <li>- human capital</li> <li>- social and organisational capital</li> <li>- manufactured capital</li> <li>- credit capital</li> </ul>   |

A range of definitions, approaches, understanding and interpretations can be observed from Table 4-5. To make the understanding, a clustering was done, and three major clusters were formed which is illustrated in Table 4-6. These three clusters show

three directions for attaining economic sustainability and are elaborated in the following sections.

1. Sustaining economic growth
2. Building natural capital
3. Building social and human capital

**Table 4-6: Direction for economic sustainability**  
Source: Author-generated based on literature review

|                         |                                   |   |
|-------------------------|-----------------------------------|---|
| Economic sustainability | Sustaining economic growth        | <ul style="list-style-type: none"> <li>- promoting community investment</li> <li>- the viable operation for a long time</li> <li>- profitability over the long term</li> <li>- Financial welfare for all the stakeholders (owner, employee, community, etc.)</li> <li>- long term benefits</li> <li>- maintaining economic growth</li> <li>- generation of monetary resources</li> <li>- man-made capital building</li> <li>- wealth (as in money, property, physical infrastructure, etc.) generation</li> <li>- The physical manifestation of information, technique and knowledge to produce goods and services.</li> </ul>  |
|                         | Natural capital building          | <ul style="list-style-type: none"> <li>- efficient and responsible use of resources</li> <li>- a selection of environmentally friendly raw materials</li> <li>- building waste disposal strategy for least impact</li> <li>- Protecting the sources of raw materials used for human needs</li> <li>- proper use of air water and land resources</li> <li>- use of renewable resources within regeneration rates</li> <li>- profitability without creating environmental concerns and harming the balance of local ecology</li> <li>- renewable use of environmental resources</li> <li>- Includes land, air, water, living organism</li> <li>- ecosystem goods and services necessary for human wellbeing and survival</li> </ul> |
|                         | Social and human capital building | <ul style="list-style-type: none"> <li>- Quality and quantity of social interaction (relationship building institutions, social cohesion, etc.)</li> <li>- the social capital building</li> <li>- building stocks of competencies, knowledge, habits, social and personal attributes (like creativity, cognitive abilities, etc.)</li> <li>- development of the ability to perform labour and produce economic values</li> <li>- often connected with education, productivity, growth and innovation</li> </ul>   |

#### 4.3.3.1. *Sustaining economic growth*

This direction of economic sustainability is focussed on economic growth and corresponds with the generation of man-made capital. Long term profitability for all the stakeholders in terms of money, property, infrastructure, etc. are the main objectives of this direction. For sustenance, it also includes promotion of community investment, the

creation of sufficient jobs, products, services, distribution of wealth, poverty level, the cost of living, employment rate, etc.

#### 4.3.3.2. *Building natural capital*

Natural capital forms the basis of all human economic activities, and its efficient and responsible use is a must for economic sustainability. These resources include land, air, water, living organism, and all other natural resources that have a potential for being used as goods and services for human well-being and survival. Building natural capital also includes activities like management of waste, pollution prevention, replacing non-renewable resources with renewable ones, etc. It aims at sustenance of economic growth without creating environmental concerns and harming the ecological balance.

#### 4.3.3.3. *Building social and human capital*

Economic activities take place within the society, and an economy cannot be sustainable without building social and human capital. It includes building the quantity and quality of social interaction, building social cohesion, the stock of competencies, knowledge, habits, social and personal attributes (like creativity, cognitive abilities, etc.). These attributes of the society contribute towards the development of the ability of a society to perform labour and produce economic values. It also connects education, productivity, growth and innovation as an important component of sustainability.

#### 4.3.3.4. *Intra-dimensional relationship - Economic Sustainability*

The proposed directions for economic sustainability have the potential of affecting each other and in this section we attempt to highlight on those interactions and relationships. Figure 4.5 presents the relation matrix for the direction of economic sustainability.

**Sustenance of economic growth vs. Building natural capital:** Sustenance of economic growth is often found to have a negative impact on natural capital and conflicts with each other. For examples approaches like manufactured demand through planned obsolescence for monetary sustenance leads to exploitation of natural resources as a significant amount of obsolete products goes to landfills.

**Sustenance of economic growth vs. Building social and human capital building:** The relationship between them depends on the context but, in most cases building social and human capital have a positive effect on the sustenance of economic growth. For example, a well-trained workforce will result in efficient production.

|  | Sustaining economic growth | Building natural capital | Building social and human capital |
|--|----------------------------|--------------------------|-----------------------------------|
| ↑ - complementary<br>↓ - conflicting<br>⇕ - mutually complementary<br>⇕ - contextual |                            |                          |                                   |
| Sustaining economic growth   |                            |                          |                                   |
| Building natural capital   | ↓                          |                          |                                   |
| Building social and human capital  | ⇕                          | ↑                        |                                   |

Figure 4-5: Interaction matrix of economic sustainability directions

Source: Author-generated

**Building social and human capital vs. building natural capital:** Social and human capital have a positive effect on the natural capital building as an aware population will take decisions that are towards protecting and conserving resources.

#### 4.3.4. Consolidated Matrix of Directions for Sustainable Design

This section presents a consolidated matrix of directions for sustainable design, which have been achieved by combining the directions for environmental, social and economic sustainability (discussed in Section 4.3.1, page 64; 4.3.2, page 70; and 4.3.3, page 73). This matrix demonstrates the various inter and intra dimensional directions' relationship. The intra-dimensional relationships have already been discussed in Section 4.3.1.5 (page 70), 4.3.2.4 (page 72) and 4.3.3.4 (page 76). The possible inter-dimensional relationships among various directions are highlighted (light coloured cells) in Figure 4.6.

##### 4.3.4.1. Inter-dimensional relationships

###### **Bridge social sustainability vs. directions of environmental sustainability:**

Promoting environmental-friendly behaviour and building stronger ethics (bridge social sustainability) has strong potential in all the 4 directions of environmental sustainability (i.e. sustaining resources, maintaining ecological systems, regulating environmental impact and developing environmental awareness). Moreover, developing environmental awareness will also complement the bridge social sustainability.

| ↑ - complementary<br>↓ - conflicting<br>⇕ - mutually complementary<br>↑↓ - contextual | Sustaining Resources | Maintaining ecological systems | Regulating environmental impact | Developing environmental awareness | Developmental social sustainability | Bridge social sustainability | Maintenance social sustainability | Sustaining economic growth | Building natural capital | Building social and human capital |
|---|----------------------|--------------------------------|---------------------------------|------------------------------------|-------------------------------------|------------------------------|-----------------------------------|----------------------------|--------------------------|-----------------------------------|
| Sustaining Resources  | ■                    |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Maintaining ecological systems  |                      | ■                              |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Regulating environmental impact   | ↑                    | ⇕                              | ■                               |                                    |                                     |                              |                                   |                            |                          |                                   |
| Developing environmental awareness  | ↑                    | ↑                              | ↑                               | ■                                  |                                     |                              |                                   |                            |                          |                                   |
| Developmental social sustainability   |                      |                                |                                 |                                    | ■                                   |                              |                                   |                            |                          |                                   |
| Bridge social sustainability  | ↑                    | ↑                              | ↑                               | ⇕                                  | ↑↓                                  | ■                            |                                   |                            |                          |                                   |
| Maintenance social sustainability   | ↓                    | ↓                              | ↓                               | ↑↓                                 | ↓                                   | ↑↓                           | ■                                 |                            |                          |                                   |
| Sustaining economic growth  | ↓                    | ↓                              | ↓                               |                                    | ↑                                   |                              | ↓                                 | ■                          |                          |                                   |
| Building natural capital  | ↑                    |                                | ↑                               | ⇕                                  |                                     |                              |                                   | ↓                          | ■                        |                                   |
| Building social and human capital   | ↑                    | ↑                              | ↑                               | ⇕                                  |                                     | ↑                            | ↑                                 | ↑↓                         | ↑                        | ■                                 |

Figure 4-6: Interaction matrix of sustainability directions

Source: Author-generated based on environmental, social and economic matrix discussed previously

**Maintenance social sustainability vs. directions for environmental sustainability:** In general, maintaining cultural, social, traditional preferences conflicts with directions of environmental sustainability. For example, the preference of people for latest products in most cases increases the obsolescence rate that conflicts with direction like sustaining resources, maintaining ecological systems, regulating environmental impacts. However, there may be few exceptions where cultural preferences have complemented environmental sustainability. For example, there are many cultural practices in India like worshipping and protecting trees and animals that complement the environmental sustainability.

**Sustaining economic growth vs. environmental sustainability:** In general, the sustenance of economic growth conflicts with environmental sustainability. Manufactured demand promoting consumerism is one of the most popular ways of sustaining economic growth that has the potential of conflicting with the environment.

**Building natural capital vs. environmental sustainability:** Strategies like efficient and long term use of natural resources, promotion of environment-friendly materials, etc. have the potential of complementing the environmental sustainability.

**Building social and human capital vs. environmental sustainability:** In general building social and human capital will make people more aware and educated; this is likely to have a complementing effect on environmental sustainability.

**Sustaining economic growth vs. Social sustainability:** The benefits of the economic growth of any country will complement developmental social sustainability (meeting basic and higher order needs of society). However, it may conflict with the maintenance of traditional and cultural practices.

**Building social and human capital vs. social sustainability:** Social and human capital building has potential of complementing bridge and maintenance social sustainability.

#### 4.4. Framework of Sustainable Design

The evolution of sustainable design in literature on one hand adds the dimensions of environment, social, and economy, while on the other hand expanded the scope from product level through lifecycle to system level as summarised in Figure 4.1 (page 63). Section 4.3.1 (page 64), 4.3.2 (page 70) 4.3.3 (73), elaborated on the dimensions of sustainability and their relationship and proposed ten directions for sustainability. These ten directions can be applied at product, lifecycle and system levels, as there are factors affecting the sustainability of a product at different levels. Table 4.7 illustrates the comprehensive framework of sustainable design spanning across dimensions and scopes.

This framework is comprehensive and covers all the major aspects of sustainability. In practice, such a framework is expected to elude all the factors and variable that needs to be considered for sustainable design.

Table 4-7: Framework for sustainable design

Source: Author-generated

| Directions for sustainability covering dimensions | Different levels at which sustainability impacting factors operate  |   |   |
|---|---|---|---|
|   | Product-level   | Lifecycle level   | System level  |
| Sustaining Resources                              | Resources consumed in manufacturing the modules/parts of product like energy and materials  | Resources consumed at different stages of the lifecycle like land, water, energy, etc.  | Resources that bring/will be consumed due to products effect on the system.   |
| Maintaining ecological systems                    | Parts/modules having potential of affecting the ecological systems and causing irreversible changes                                   | Lifecycle stages are causing irreversible changes like biodiversity loss, ecological cycle's disturbance, etc.  | Factors that affect the system impact on ecological systems   |
| Regulating environmental impact                   | Toxic and hazardous substances waste, generally reversible.   | Lifecycle phases where production of toxic and hazardous substances, waste.   | System in production of environmental impact like toxicity production, waste generation                             |
| Developing environmental awareness                | Lack of information which can be helpful for the decision makers  | Lifecycle stages where information is most needed for environmental friendly decision-making  | Information availability lead to environmental friendly decision making within the system                           |
| Developmental social sustainability               | Product and its use that influences the fulfilment of basic and higher-order needs  | Fulfilment of basic and higher order needs of stakeholders at different stages of the lifecycle   | System-level factors affecting the fulfilment of basic needs and higher order needs.                                |
| Bridge social sustainability                      | User behaviour while using the product is leading to wastage of resources, disturbance in ecology, etc.                               | Stakeholders' behaviour at different lifecycle stages of the product is leading to wastage of resources, disturbance in ecology.  | Stakeholders' behaviour is leading to wastage of resources, disturbance in ecology at system level                  |
| Maintenance social sustainability                 | Affecting the user preferences that they would like to be maintained like traditions, cultural preferences, religious practices, etc. | Stakeholders' preferences that they would like to be at different life cycle stages of product  | Stakeholders' preferences that they would like to be maintained are affected within the system                      |
| Sustaining economic growth                        | Products' features that do not add value to the producer and consumer - identify features that add value                              | Factors that has potential of increasing the products value for the customer as well as producer across the lifecycle stages  | Factors that can strengthen the product's market position, competition and future long-term business opportunities. |
| Building natural capital                          | Product features that the not efficient and has a potential of improvement contributing to resource efficiency                        | The factors that are not efficient across the lifecycle stages and leads to wastage of resources harms environment and ecology  | Factors that are not efficient and leads to wastage of resources, - opportunity for efficient technologies          |
| Building social and human capital                 | Product features that have potential of building competencies among user by providing information, knowledge                          | Factors across product's lifecycle (introduction, growth, maturity and decline) that have potential of building competencies among user by providing information, knowledge | System that are affected by the product building social and human capital   |

## 4.5. Conclusion

This chapter presented the development of a comprehensive framework for sustainable design (concerning RQ1 and OB1). The development was based on the content analysis of various definitions and understating of sustainability, and its dimension presented by literature. Ten major directions for sustainability were derived out of which four directions concerned environmental sustainability, three concerned social sustainability and 3 covered economic sustainability. It was also found that these ten directions for sustainability have a potential of affecting each other. The chapter explored four types of inter and intra dimensional relationships (i.e. complementary, conflicting, mutually complementary, contextual). For convenience of use, this was presented in the form of an interaction matrix, which can very easily reflect the general inter and intra dimensional relationship. However, these inter and intra dimensional relationships pointed out are limited, and there is a scope for more types of relationship depending on the context (design problem at hand) and application.

- These ten directions for sustainability have a potential effect on the factors/variables at product, lifecycle and system levels. Table 4-7 is the proposed working framework for sustainable design and covers RQ1 and OB1. This framework provides a framework for sustainability analysis and can be helpful at synthesis phase of creative design.

## Chapter 5

(Phase - 2)

# Exploring Mental Models and Approaches Adopted by Creative Designers towards Sustainability and Sustainable Designing

This chapter attempts to explore the perceptions, mental models and problem-solving approaches of novice creative designers towards sustainable design (concerns RQ2, RQ3 and OB2, OB3, page 46). The conception of the mental model about any concept is considered the most important aspect of design training and education. Literature doubts the mental models of creative designers about the philosophy of sustainable design to be biased and incomplete. Moreover, a limited number of research reflects the problem-solving approaches of creative designers when the condition of sustainability comes into the picture. This chapter reports the empirical study conducted to explore the existing perceptions and mental models of creative designers about the concept of ‘sustainability’ and ‘sustainable design’ in the background of existing literature and their training. It also attempts to investigate how with the existing perception and mental model creative designers approach a sustainable design problem.

## 5.1. Introduction

Integration of sustainability issues in the practice of creative design is considered a promising way to achieve sustainability (Sherwin, 2004). In chapter 1, section 1.3.2 (page 14) it has been pointed out that one of the issue towards integrating sustainability philosophy with the practice of design is the lack of understanding of the existing mental model and approaches of creative designers towards sustainability and sustainable design. In Chapter 2, section 2.4 (page 34) it has been shown that the understanding of sustainability and sustainable design available in the literature is very diverse and confusing. On one hand, it corresponds with the philosophy of sustainable development that is considered vague and elusive; while on the other hand it is seen as the broadening of scope from green design through eco-design to sustainable design. A comprehensive understanding of sustainable design should include both these views as illustrated in figure 2.10 (page 35). However, many researchers believe that this comprehensive understanding is limited to theory and is not used in practice (Kjøllestad et al., 2012). They argue that in practice sustainability is still considered either optional or as an added set of constraints (limiting the design space) and its understanding usually stops at environmental issues only (Kjøllestad et al., 2012).

According to Frisk and Larson (2011), one of the prominent reasons to this is the wrong interpretation and conception of the knowledge (Frisk & Larson, 2011). Vanasupa and Burton (2010) suggests that this wrong or partial conception of knowledge is reflected in the mental model of designers (Vanasupa et al., 2010). They argue that since most of our actions and decisions are guided by the mental model of reality that we consciously or unconsciously carry, a flawed or a partial mental model of sustainable design among designers will result in decisions and actions that are biased and partial (Vanasupa et al., 2010). Moreover, they deduce that one of the possible points where these flawed and partial mental models are conceived is during design training.

This chapter reports an empirical study conducted, first part (section 1) of which was focussed on exploring the perceptions and mental models of novice creative designers (design students) about the philosophy of sustainability and sustainable design. It was posited that there are significant gaps in perceptions and mental models of designers regarding sustainability and sustainable design.

The second part (section 2) of the empirical study attempted to explore the problem-solving approaches of novice designers given a sustainable design problem. As pointed out in the previous paragraphs, the mental model of a concept plays a very important role in decision making. A flawed or partial conception of the concept will be reflected in the actions. With this background, the study attempted to capture how novice creative designers make use of their existing perceptions and mental models in the practice of sustainable design. Given a sustainable design problem, how they approach it and what are the difficulties they face during the creative design phase?

Creative design as an activity has been well studied under normal circumstances that have already been discussed in section 2.6.2 (page 48) of chapter 2. However, limited studies have been published which reports the effect of adding sustainability conditions or sustainability factors in the creative design phase. This phase is considered to be a multifaceted (Oxman, 1996 as cited in (Taylor et al., 2007)) and the additional norm of incorporating sustainability into products is expected to add to its complexity. It is likely to affect the problem-solving approaches of creative designers. The reported empirical study intends to understand this effect. The study is expected to provide valuable information that may be useful in developing support tools for sustainable design. Apart from this, the study is expected to highlight on the generic methodology followed by them (is it similar to the traditional methodology or is different), instances where support is required as well as the kind of support anticipated.

The subjects chosen for this study were novice designers who were in the final semester of their study either at undergraduate or postgraduate levels from three Indian design schools. The existing literature reports many empirical studies on the difference between novice and expert designers (Atman et al., 2005). However, this study focuses only on the approach of novice designers while practicing sustainable design. Following were the research question and objectives explored in this empirical study from amongst those listed in Chapter 1 in this thesis (page 16).

**RQ2:** What are the existing perception and mental model of novice creative designers about the concept of sustainability and sustainable design?

**RQ3:** How novice creative designers approach sustainability given a design problem in the background of their existing training and available literature?

**OB2:** To explore the existing perception and mental model of novice creative designers about the concept of ‘sustainability’ and ‘sustainable design’ in the background of their existing design training.

**OB3:** To explore the problem-solving approach of creative designers given a sustainable design problem.

## 5.2. Material and Methods

The framework of empirical study has already been discussed in section 3.3.2 (page 58) and illustrated in figure 3.5 (page 59). The study employed an instrument specially designed for the purpose consisting of a questionnaire and a problem-solving exercise, discussed in section 5.2.3.

Creative Designers tend to follow certain stages during the creative design phase (conceptualisation phase), as illustrated in figure 1.3 (page 7). These stages are linear initially but as they proceed in time it becomes iterative, and there is a transition between different activities. Apart from RQ2 and RQ3 stated above, the empirical study also attempted to explore what type of information a creative designer look for at the problem formulation stage? Is that information available to them readily? Researchers attempts to understand, that with the added set of sustainability condition what extra effort, or what extra time it is going to the which part of the cognitive activity, and will a support system will help them in getting rid of it ?

### 5.2.1. Working Posits

The following study assumes that the actions and decisions made during problem solving will reflect the mental model of designers giving valuable information about gaps in understanding (on part of the designer) and conception of the concept under study. The study explores the following two working posits reproduced from the list of posits listed on page 16 of this thesis.

**P1:** Existing perception and mental model of creative designers about the concept of sustainable design is biased towards the environmental dimension of sustainability.

**P2:** Existing morphological ‘approach’ of novice creative designer to sustainability given a sustainable design problem is through the environmental dimension.

The environmental dimension of sustainability here includes the process of reducing the environmental impact of products to be designed and increasing their environmental efficiency through approaches like material and toxicity reduction. The perception here is the underlying foundation on which mental model is built by the designer, and ‘approach’ is with respect to the intended flow chart to be adopted. Together they form what is the morphology of designing sustainable products being practised. A heuristic analysis of the curriculum being adopted in design schools – for example – yielded a limited understanding of where to start and how to incorporate the variables that matter in sustainability.

### 5.2.2. Participants and Study Location

Purposive sampling was done for selection of the subjects based on ease of access and availability. The participants of this study were undergraduate (Bachelor of Design-BDes) and postgraduate (Master of Design-MDes) students from design program of 3 design schools in India as shown in figure 5.1.

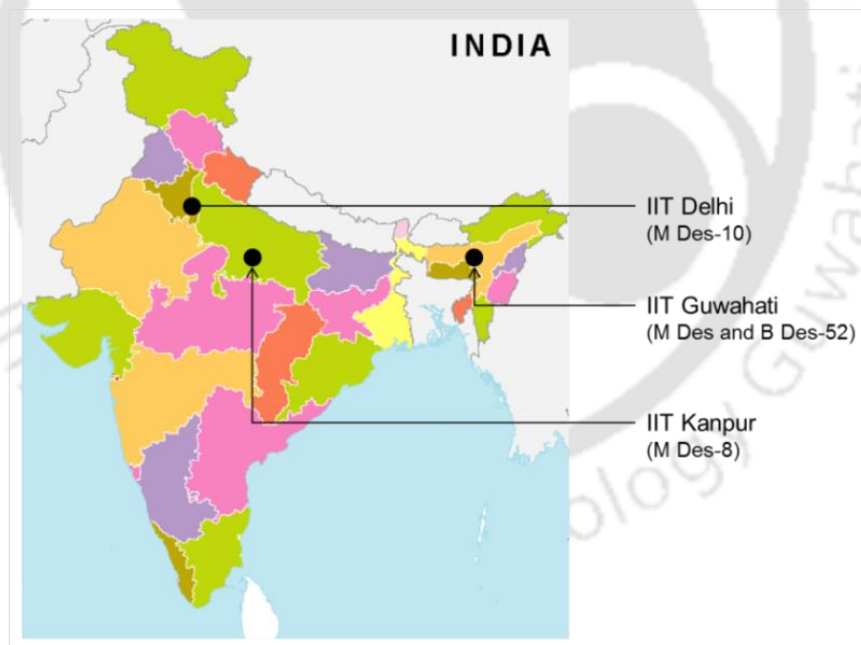


Figure 5-1: Study location and subjects involved

Source: Adapted from (<http://www.dreamstime.com/royalty-free-stock-photography-map-india-more-authentic-image4884257>)

The study considered students who have two years or more than two years of association with design discipline. Base on this, the following categories of students were selected.

1. Master of Design (MDes) students – Final semester students
2. Bachelor of Design (BDes) students – 3<sup>rd</sup> year and above.

The study was carried out by physically going to the subjects' location and conducting the survey. As the study conducted was mainly qualitative in nature a total of 70 participants were involved in section 1 of the study, and 24 participants were involved with section 2 of the study.

### 5.2.3. Method of Investigation: Instrument Used

An instrument consisting of a questionnaire (Section 1), and a problem-solving exercise (Section 2) was designed for data collection. The actual instrument used for the survey is presented in Appendix 1. The following section elaborates on both the sections.

#### 5.2.3.1. *Instrument Design: Section-1*

This part of the instrument comprised 12 questions—both objective and subjective types. Part of the questionnaire was adapted from a similar survey conducted in 2005 for engineering students (Azapagic, Perdan, & Shallcross, 2005). Most of the questions were modified to suit the needs of this research. Following are the main parts of the questionnaire:

1. **Basic information regarding participants** was covered in questions 1 and 2 and consisted of information on age, gender, educational background, design experience, academic degree, and the name of the educational institution.
2. **Exposure to Sustainability Education** was covered in questions 3 and 4. Sustainability education is imparted in a design program, either as a separate course or as parts of other related courses. The other way of exposure is through short-term courses, workshops, seminars, and conferences.
3. **Participants' definitions of sustainability** and sustainable design were obtained from question 5 (subjective-type question). The participants' were asked to define sustainability from the following point of view:
  - a. As a creative product designer
  - b. As a user of hired taxi
  - c. As a citizen of the country
  - d. As a universal human being
4. **Perceptions about related concepts and their influences on sustainable design** were explored in question 6 where participants were asked to describe how concepts like green design, eco-design, environmental design, etc. relate to Sustainable Design.

5. **Self-evaluations of knowledge** about Sustainable Design and its perceived importance in design were covered in questions 7 and 8.
6. **Participants' perceptions and evaluations of their respective degree program** regarding sufficient input for Sustainable Design were covered in question 9.
7. **Participants' attitudes towards using sustainable products** were covered in questions 10 and 11. Question 10 asked the participants, how frequently they are willing to pay more for products that are environment-friendly/eco-friendly/sustainable. Question 11 asks them to recollect any one product bought by them that has sustainability taken into consideration by its manufacturer.
8. **Participants' opinions about the sustainability of certain existing products** were covered in question 12. In this question, pictures of three existing products were shown to the participants and were asked for their opinion on its sustainability. They were asked to rate the sustainability on a scale of 1 to 10 where 1 represent 'unsustainable' and 10 represents 'ideally sustainable'. They were also asked for extended comments justifying the rating.

#### 5.2.3.2. *Instrument Design: Section-2*

This section contained a design problem that was aimed at studying how sustainable design is approached in practice by creative designers. It consisted of following parts.

1. **A design problem with relevant information:** To design a sustainable mobile phone, participants had to suggest ways of improving sustainability through problem solving and conceptualization.
2. **A fill up sheet to list variables related to sustainability:** Participants were asked to prepare a list of design variables that significantly affect product sustainability, including variables that the participants have considered during conceptualisation or that they feel should be considered.
3. **Process flow map/diagram:** Once the problem-solving exercise was over, respondents were asked to re-think how they solved the given problem and drew a process flow diagram. They were given the freedom of expressing in whatever way they prefer.
4. **Blank sheets** were provided to subjects for exploring various solutions and problem-solving methods.

A snapshot of Questionnaire (Section 1) is shown Figure 5.3 and the problem-solving exercise (Section 2) is shown in Figure 5.4. Appendix 1 presents the actual instrument used for the study.

**Section 1**  
 The main objective of this section is to comprehend your understanding and perception about the concept of 'Sustainable Design'.

1. Please fill in the table below:

|                                | Degree name with discipline       | Name of the Institute  |
|--------------------------------|-----------------------------------|------------------------|
| Current degree                 | M.DES (INTERACTION & GAME DESIGN) | IIT KANPUR             |
| Last degree completed (if any) | B.E. (ELECTRICAL)                 | THAPAR UNIVERSITY (PB) |

2. Number of years you are associating yourself with the discipline of 'Design'. *22 yrs. Since Childhood.*

3. Did your current degree have any course/courses related to sustainability in design? (Tick Yes / ~~No~~)

4. Have you attended any conference/workshop/seminar/short term course/symposium etc. related to 'Design for sustainability' in the last 4 years? (Tick ~~Yes~~/ No)

5. Define in 2-3 sentences as to what do you understand by the term 'sustainability' from the following point of view? In case your answer is same in all the below mentioned cases write 'same'.

As a creative product designer - *Sustainable design is*  
 - *efficient (material wise)*  
 - *cooperative (environment & user)*  
 - *life cycle of the product shouldn't be a single loop.*  
*To me*  
*Sustainable design is like mythological kind phenomena.*

Figure 5-2: Snapshot of the questionnaire (Section 1 of the instrument)  
 Source: Respondent-generated

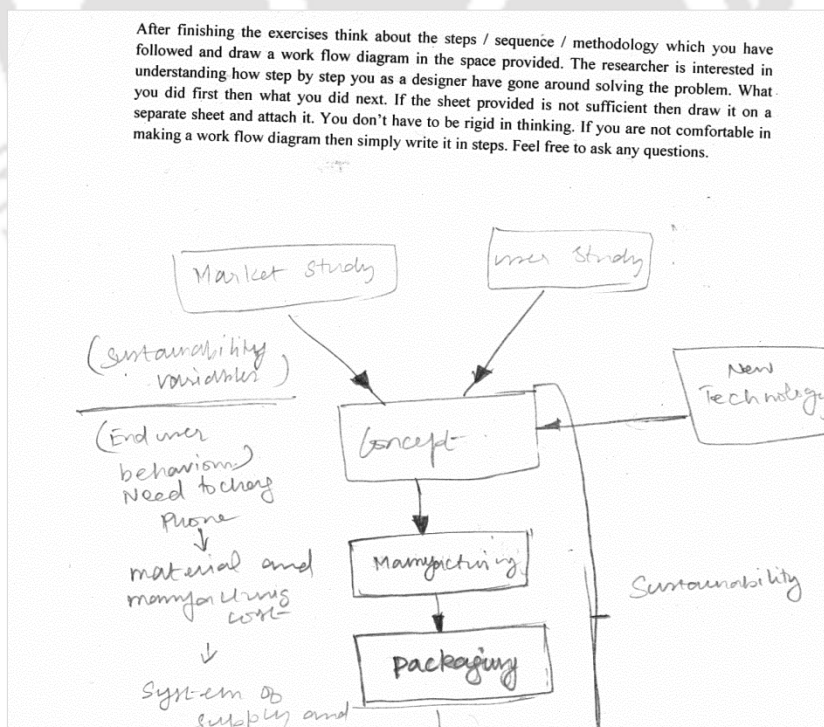


Figure 5-3: Snapshot of the problem-solving exercise (Section 2 of the instrument)  
 Source: Respondent-generated

#### 5.2.4. Experimental setup and procedure

The study was conducted in the design studios of the institutions visited. A typical study setup is shown in Figure 5.5. Before the study was initiated, prospective participants were informed about its purpose and the necessary time commitment. Those who voluntarily agreed to take part in the study were selected to participate. Initially, the questionnaire (Section 1) was distributed to participants, and the moderator provided explanations regarding the questions. Respondents were given 30 minutes to fill out the questionnaire.

Once Section 1 was completed, Section 2 (problem-solving exercise) was distributed. Once again, the moderator explained the problem statement and reviewed the sheets to complete. The time given for Section 2 was 2 hours and 30 minutes. During the problem-solving exercise, participants were allowed to ask questions and express any doubts. They were permitted to take breaks during the session as needed. An announcement that only 30 minutes remained was issued. At the end of the session, all sheets were collected and marked. Caution was taken not to disturb the sequence of conceptualisation as it reflected how participants solved the problem. Figure 5.6 illustrates the procedure followed for the study.



Figure 5-4: Study setup

Source: Photo clicked during the empirical study

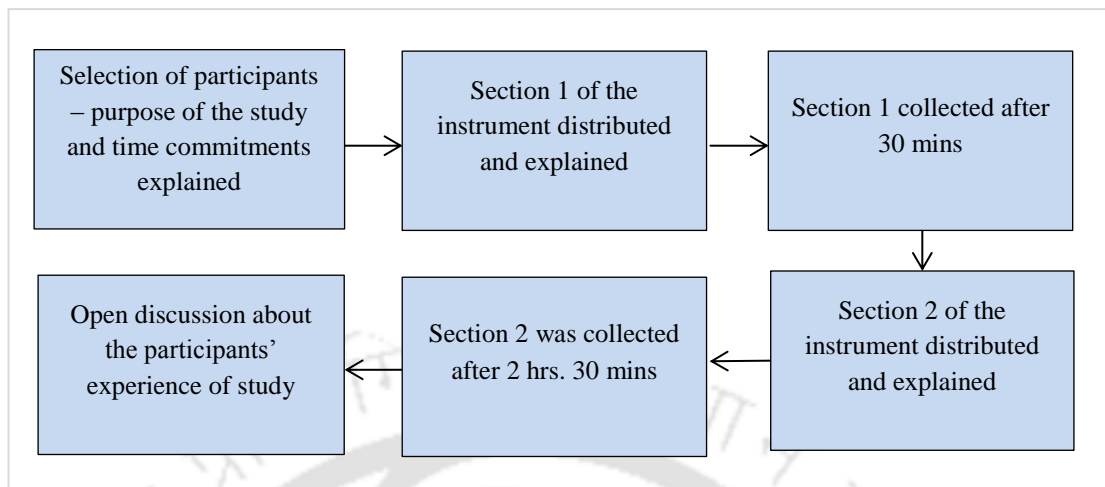


Figure 5-5: Procedure followed for data collection

Source: Author-generated

At the end of the session, an open discussion was carried out about their whole experience of the study. Total numbers of the participant for Section 1 were 70, and for Section 2 were 24.

### 5.3. Analysis and Results

The method of analysis was mainly qualitative followed by quantitative, as discussed in the following sections.

#### 5.3.1. Analysis - Section 1

For objective type questions in Section 1, descriptive statistics was used for analysis. For the subjective type question in Section 1 (i.e. question 5), content analysis was used, as elaborated in the following section.

##### 5.3.1.1. Method of Analysis

For content analysis initially, the entire content was read by two evaluators (E1 and E2), and keywords and phrases were underlined. Then, both evaluators separately evaluated the content according to the evaluation sheet shown in Figure 5.6 (see Appendix 2). Once the evaluations were complete, both the evaluators compared evaluation sheets and discussed any differences; then, they continued to evaluate such cases separately. Both evaluators were senior researchers in the field of sustainable design.

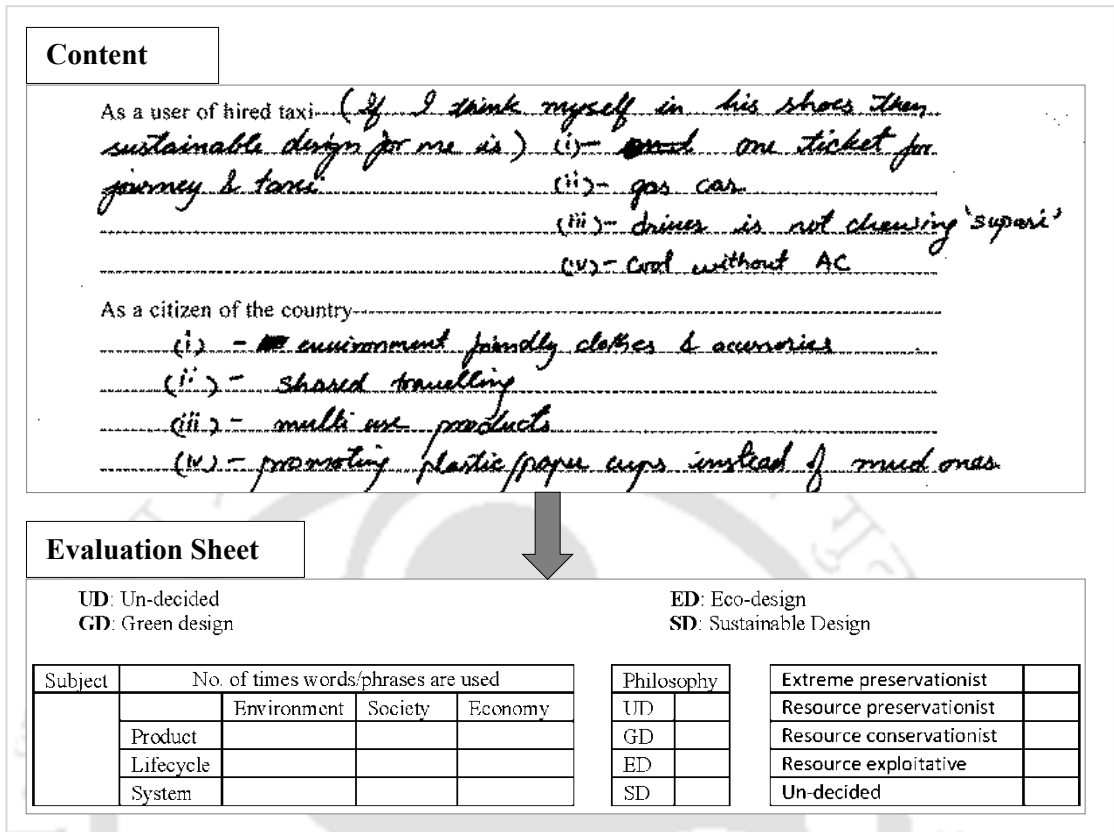


Figure 5-6: Sample content taken from a participant's response and the evaluation sheet (UD: undecided, GD: green design, ED: eco-design, SD: sustainable design)

Source: Author-generated

### 5.3.1.2. Results of Analysis

This section presents the results of the data analysis.

- Basic Information (Q1):** The total sample size was 70, of which 49 were males, and 21 were females, the age range was 19-30 years with mean 22.64 years. Further, 32 participants were enrolled for MDes degree, and 38 were enrolled for BDes degree. Table 5-1 shows the distribution of participants according to degree and Institute (IITG- Indian Institute of Technology Guwahati, IITD – Indian Institute of Technology Delhi, IITK – Indian Institute of Technology Kanpur).

Table 5-1: Age distribution of the subjects

Source: Author-generated

| Degree             | MDes |      |      | Bdes |
|--------------------|------|------|------|------|
| Institution        | IITG | IITD | IITK | IITG |
| No of Participants | 14   | 10   | 8    | 38   |

2. **Association with the field of design (Q2):** The question was intended to know the participants' experience of design (including academics and work experience). All the subjects had 2 or more than two years of experience with a mean of 3.43. Figure 5.7 shows the experience distribution of the participants.

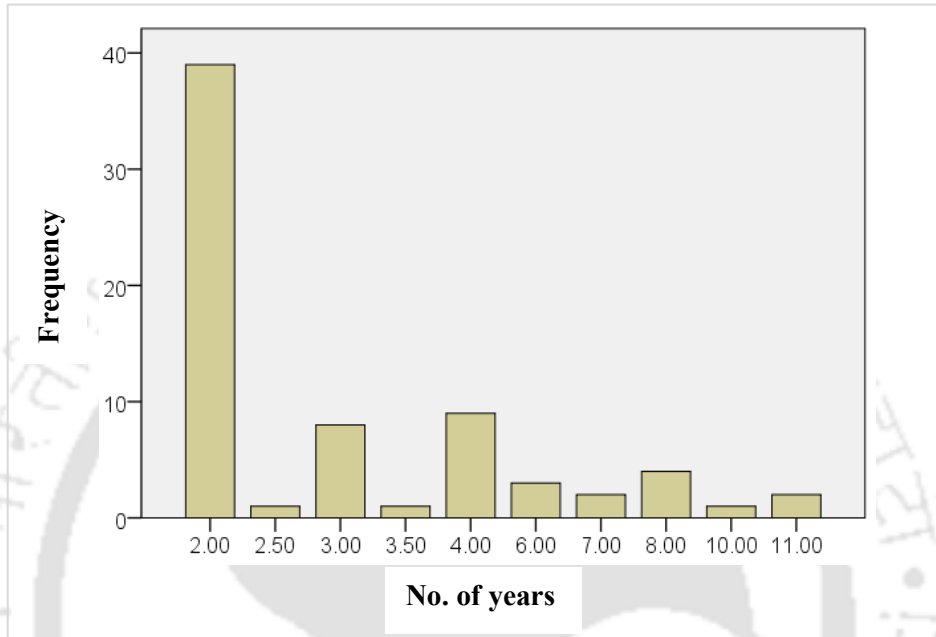


Figure 5-7: Association with the field of design (design experience)  
Source: Author-generated

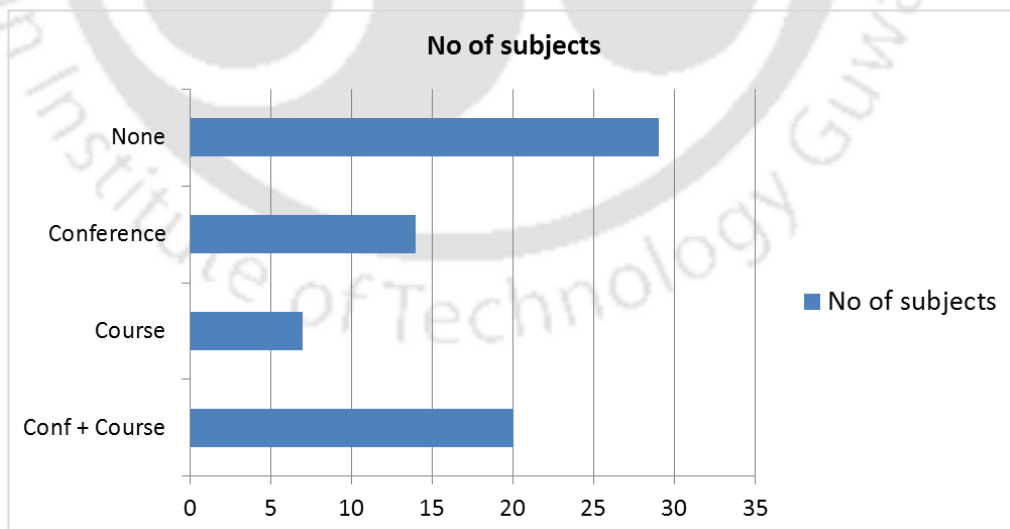


Figure 5-8: Exposure to sustainability in design education  
Source: Author-generated

3. **Exposure to sustainability in the design program (Q3):** Sustainability education in India is imparted in design program either as a separate course or part of some other

courses. Many a times it is also propagated through short-term courses, conferences, seminars, and symposium. Out of 70 respondents, 43 (60%) reported that their degree program did not have any course/courses related to sustainable design.

4. **Exposure to sustainability through other sources (Q4):** Fifty percent (36 of 70) of respondents reported to have attended sustainability-related conferences/seminars/workshops. Figure 5.8 shows the consolidated distribution of participants according their sources of sustainability exposure. These results are indicative of a lack of sustainability integration within the design program of surveyed institutions.
5. **Participants' definition of sustainability (Q5):** This was a subjective type question for which content analysis was done by two evaluators E1 (evaluator 1) and E2 (evaluator 2). The evaluation reflected that participants used words or phrases related to environmental issues often while describing their understanding of sustainability from various perspectives. Figure 5.9 illustrates the distribution of words/phrases based on frequency in the content.

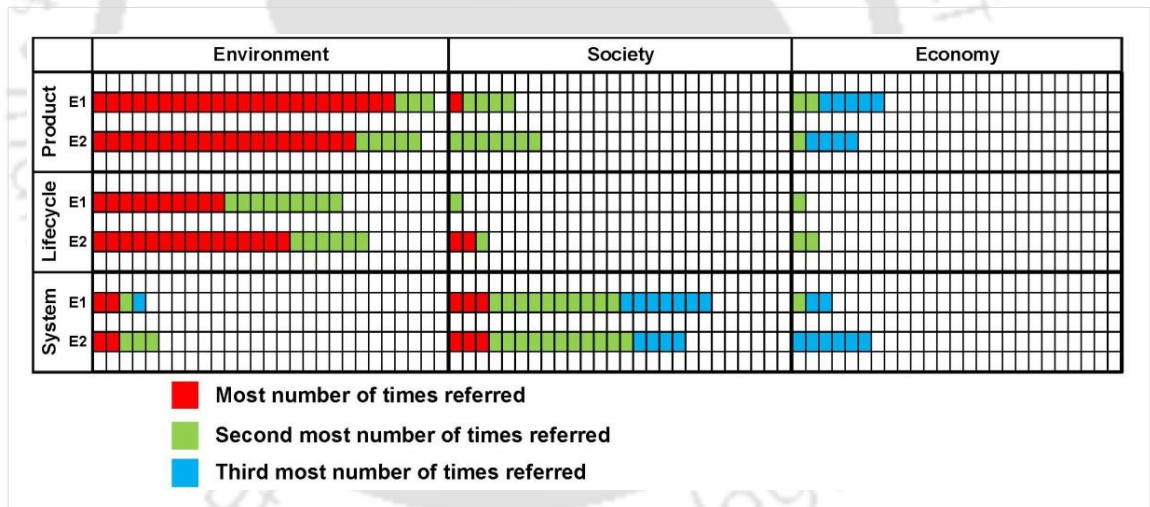


Figure 5-9: Distribution of words/phrases as revealed by the content analysis by two evaluators  
 Source: Author-generated

It was further revealed that most of the respondents' description of the sustainable design was closer to the concept of either green design or eco-design (see Figure 5.10). This is supported by the previous observation of content analysis.

Further, it was observed that most of the subjects took either resource conservationist or resource exploitative (concerning radical manipulative worldview as discussed in section 2.3.1, page 31) stand on sustainability as shown in Figure 5.11.

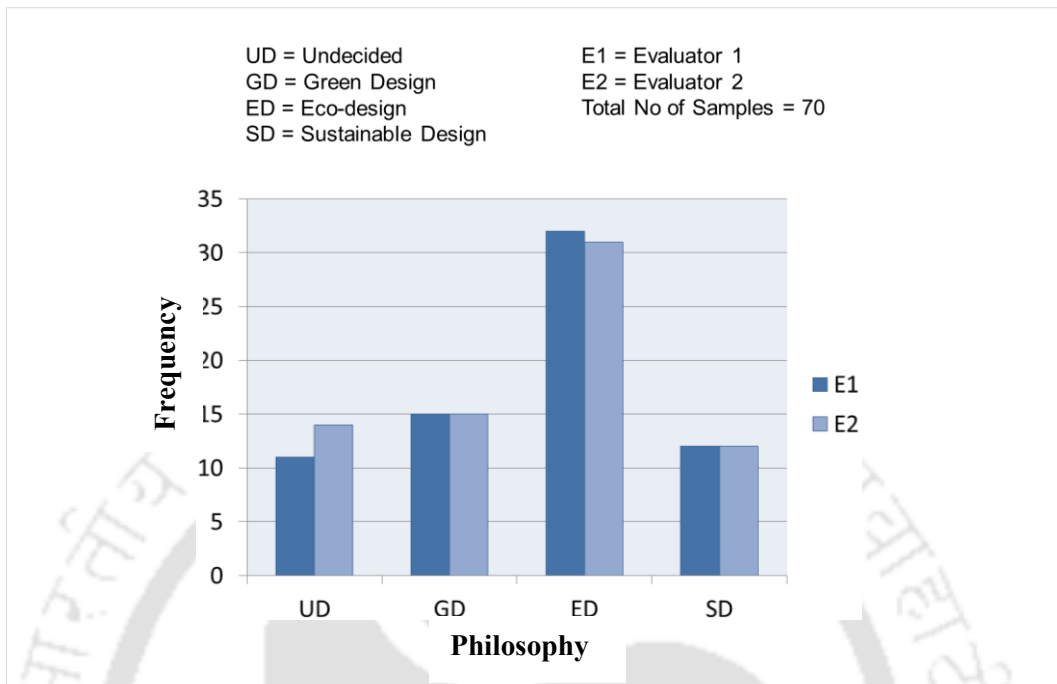


Figure 5-10: Distribution of philosophical understanding of respondents  
Source: Author-generated

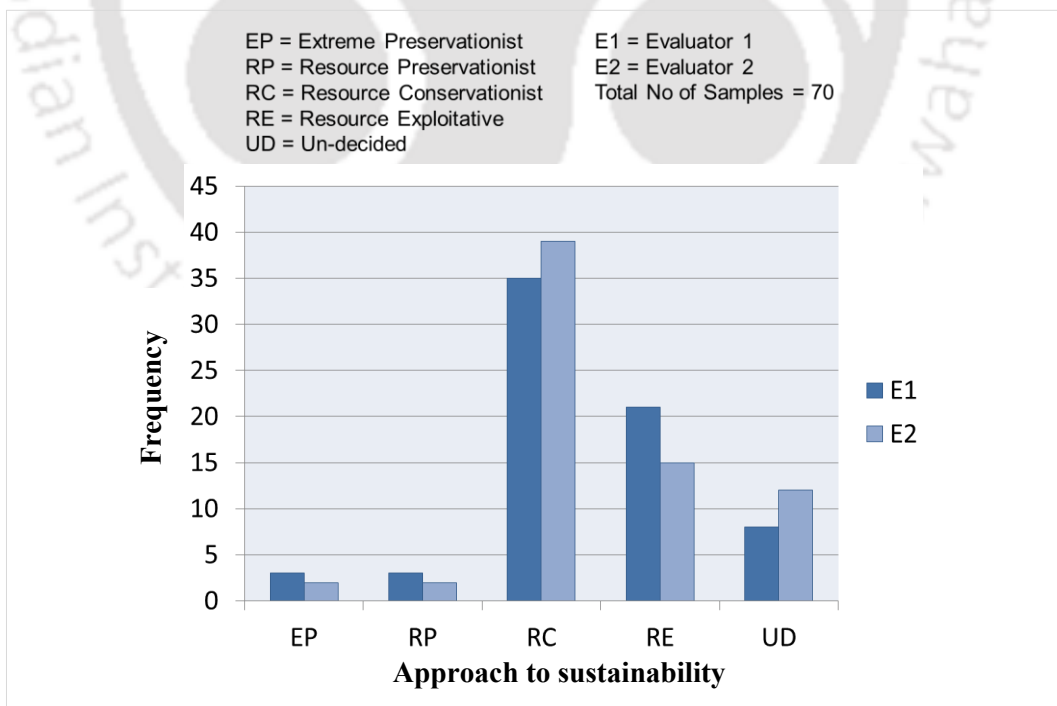


Figure 5-11: Distribution of 'approach to sustainability' reflected by respondents  
Source: Author-generated

These findings indicated the limited understanding of sustainability philosophy by participants which is biased towards environmental dimension and is closer to the concepts of green design and eco-design. One of the probable reasons for this bias is the historical rooting of sustainability into environmentalism. Moreover, the concepts of green design and eco-design are well established, but sustainable design is still in its evolutionary stages. The other possible explanation may be the lack of exposure of respondents about the comprehensive nature of sustainable design philosophy.

6. **Influence of related concepts on the sustainability of a product (Q6):** There are many terms/concepts in the literature that are often associated with the concept of sustainable design. Some of them are green design, eco-design, design for environment, carbon footprint, ecological footprint, design for sustainable development, design for disassembly, design for cleaner production, etc. Figure 5.12 illustrates their relationship. From the figure, it can be observed that sustainable design encapsulate the philosophy of eco-design, design for environment and green design. This relationship mapping is very important towards understanding the comprehensive nature of sustainable design. Respondents were expected to understand this encapsulation while rating the influence of various concepts on products' sustainability

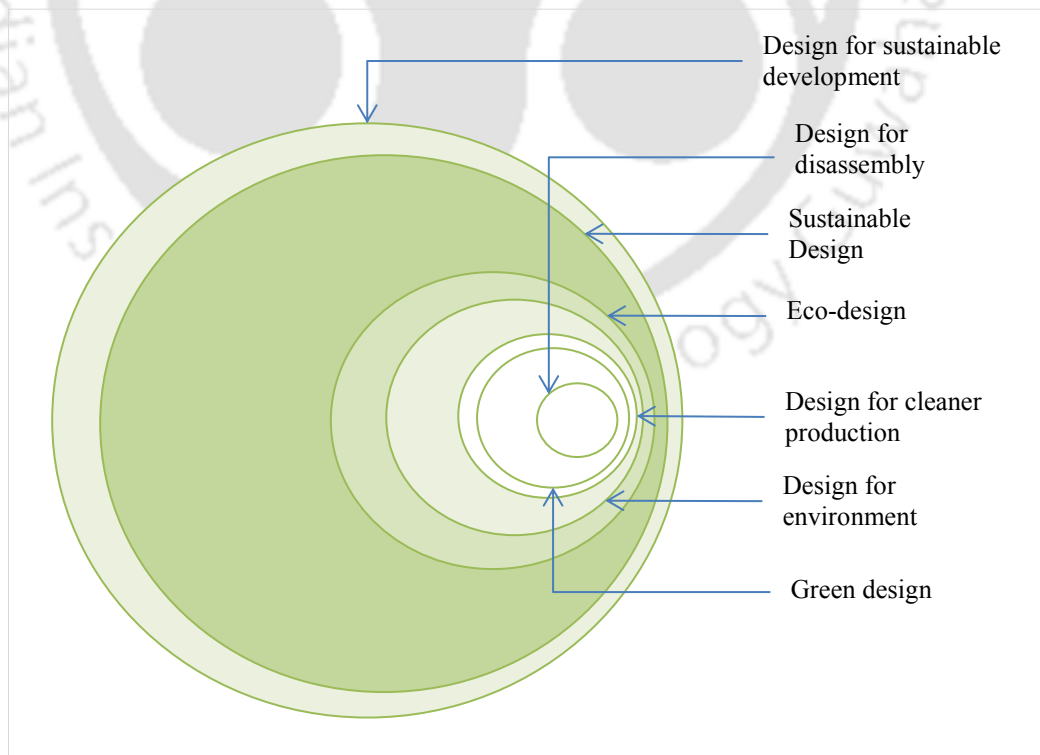


Figure 5-12: Relationship between terms/concepts related to sustainable design  
Source: Author-generated based on consolidated findings from literature

The question 6 of the questionnaire was intended to understand how the participants perceive these terms in relation to the sustainability of a product. Respondents were first asked to tick the terms that are familiar to them and then rate each of them (in percentage) according to their influence on products' sustainability.

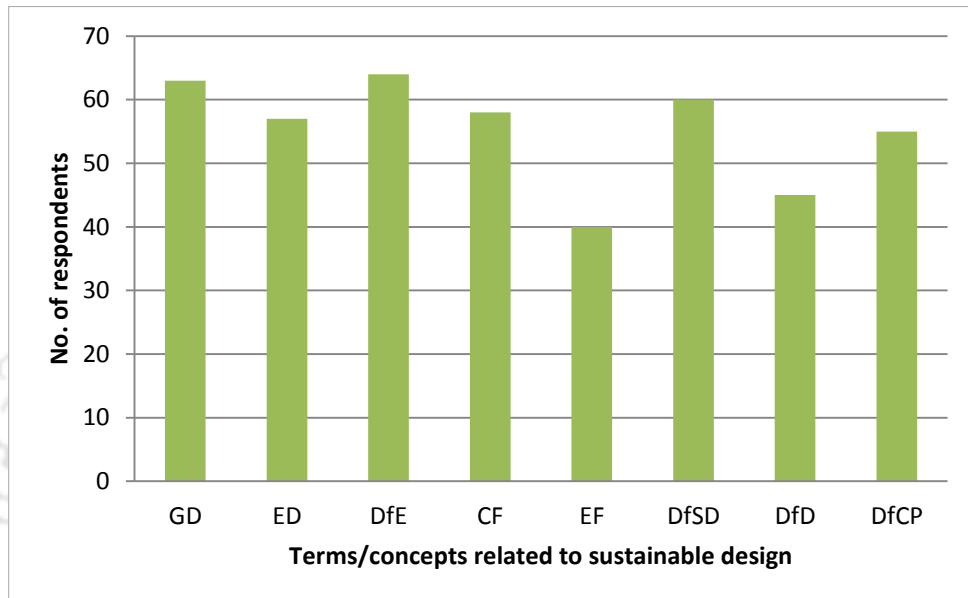


Figure 5-13: Familiarity of respondents with GD-green design, ED-eco-design, DfE-design for environment, CF-carbon footprint, EF-ecological footprint, DfSD-design for sustainable development, DfD-design for disassembly, DfCP-design for cleaner production

Source: Author-generated

*Green Design:* Out of 70 participants 63 showed their familiarity with this concept. Nearly 66% (42 out of 63) respondents perceive that green design has 60% or more influence on the sustainability of a product (see Figure 5.14).

*Eco-design:* Out of 70 participants 57 showed their familiarity with this concept and 84% (48 out of 57) rated it from 40% to 80% influence on the sustainability of a product. Seventy percent (40 out of 57) respondents rated its influence as 60% and above (see Figure 5.15).

*Design for Environment:* Out of 70 participants, 64 showed their familiarity with this concept and according to 67% (43 out of 64) respondents it has 60% or more influence on sustainability of a product (see Figure 5.16).

*Design for Sustainable Development:* Out of 70 participants, 60 showed their familiarity with this concept and 75% of respondents rated it in the range of 50% to 90% for its influence on products' sustainability.

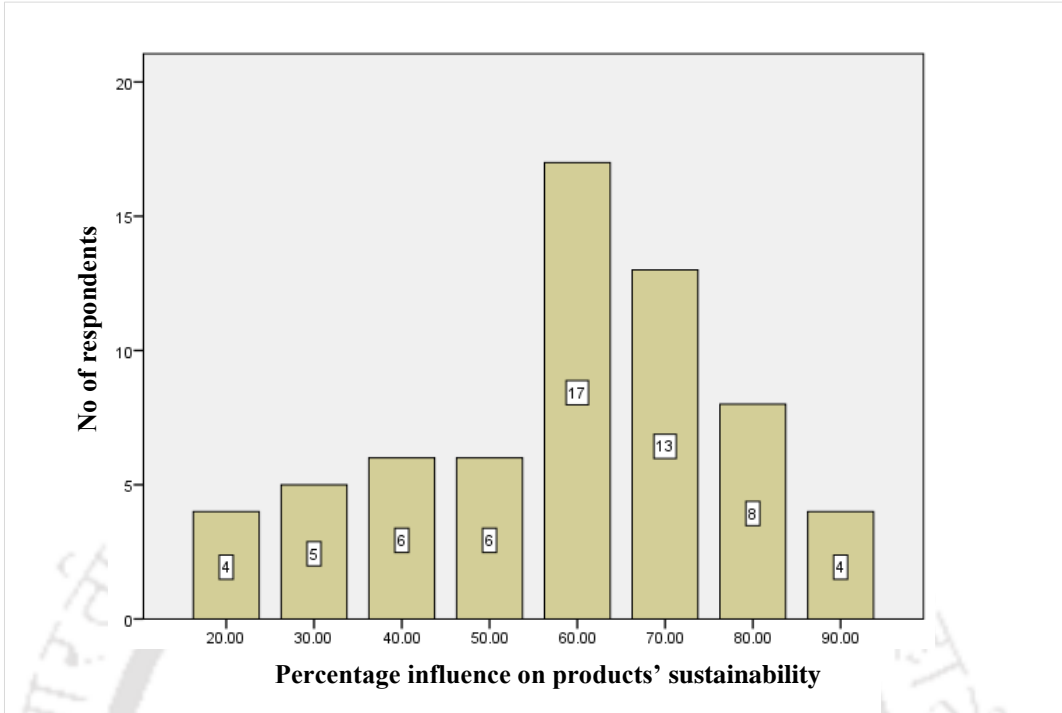


Figure 5-14: Influence of Green Design on products' sustainability (in %) according to respondents  
Source: Author-generated

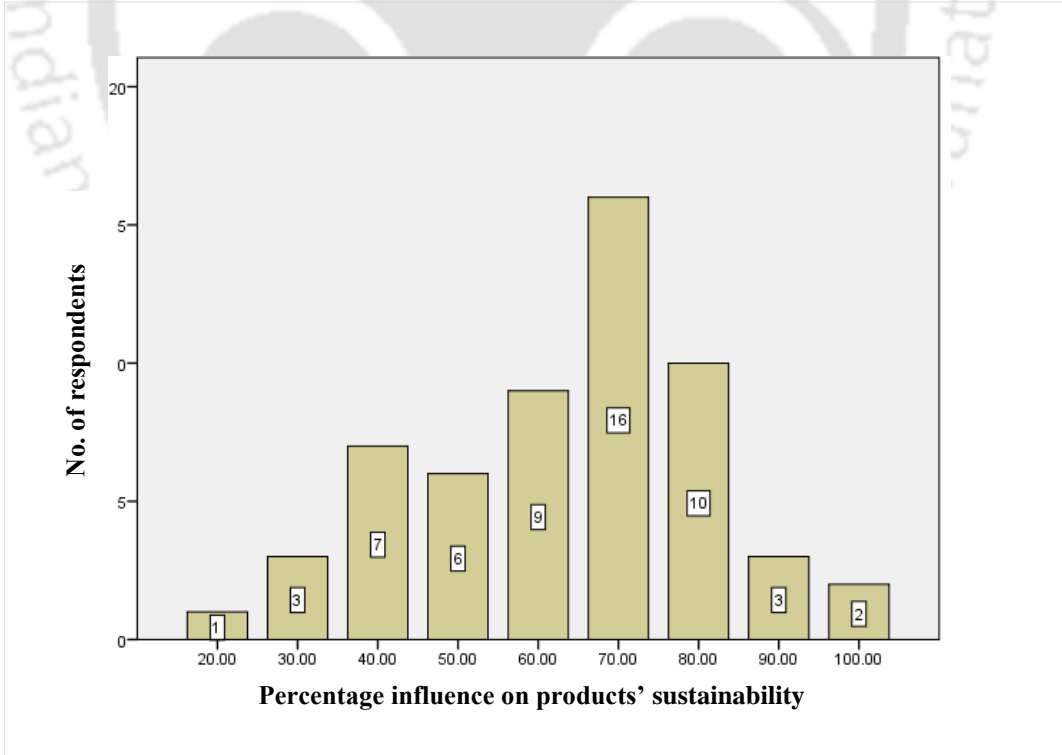


Figure 5-15: Influence of Eco-design on products' sustainability (in %) according to respondents  
Source: Author-generated

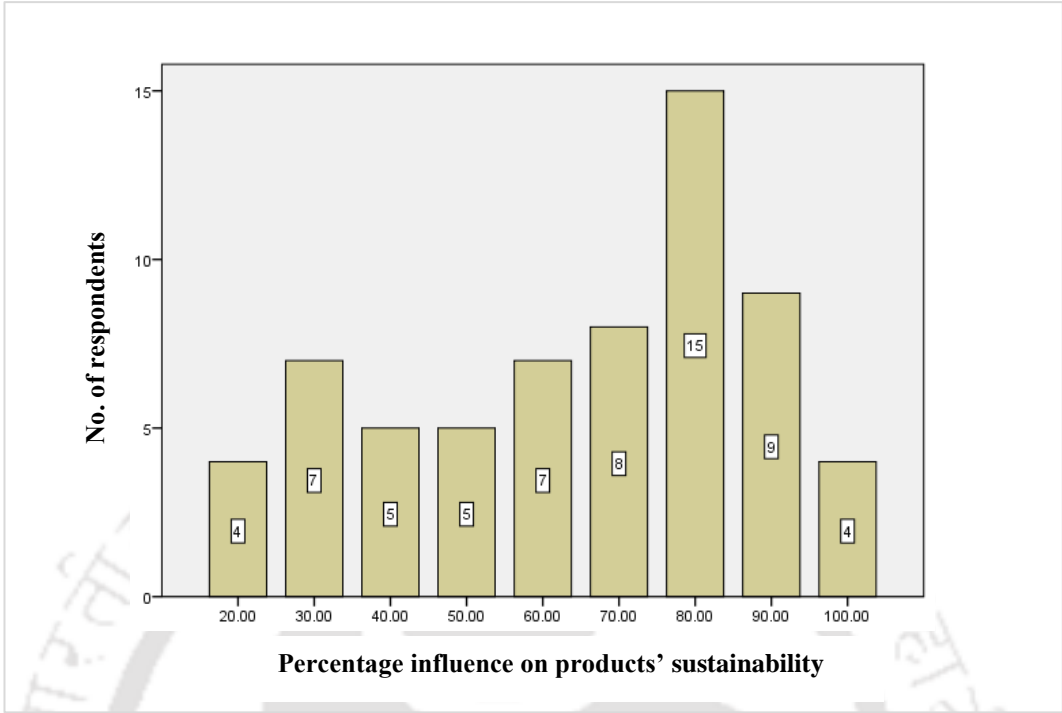


Figure 5-16: Influence of design for environment on products' sustainability (in %) according to respondents

Source: Author-generated

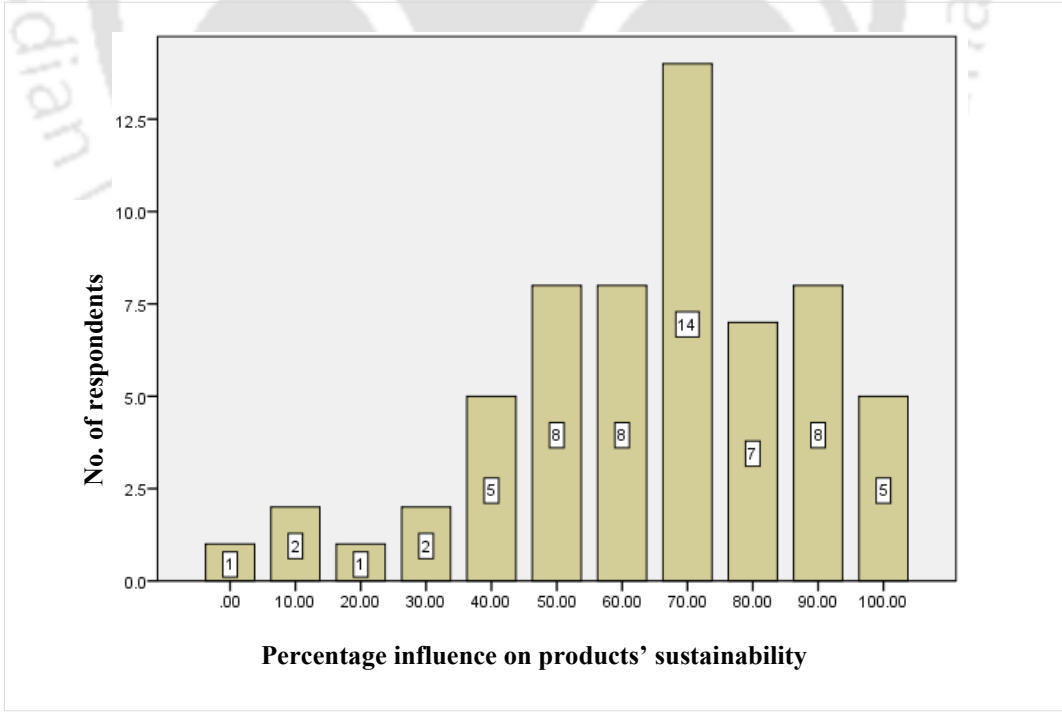


Figure 5-17: Influence of design for sustainable development on products' sustainability (in %) according to respondents

Source: Author-generated

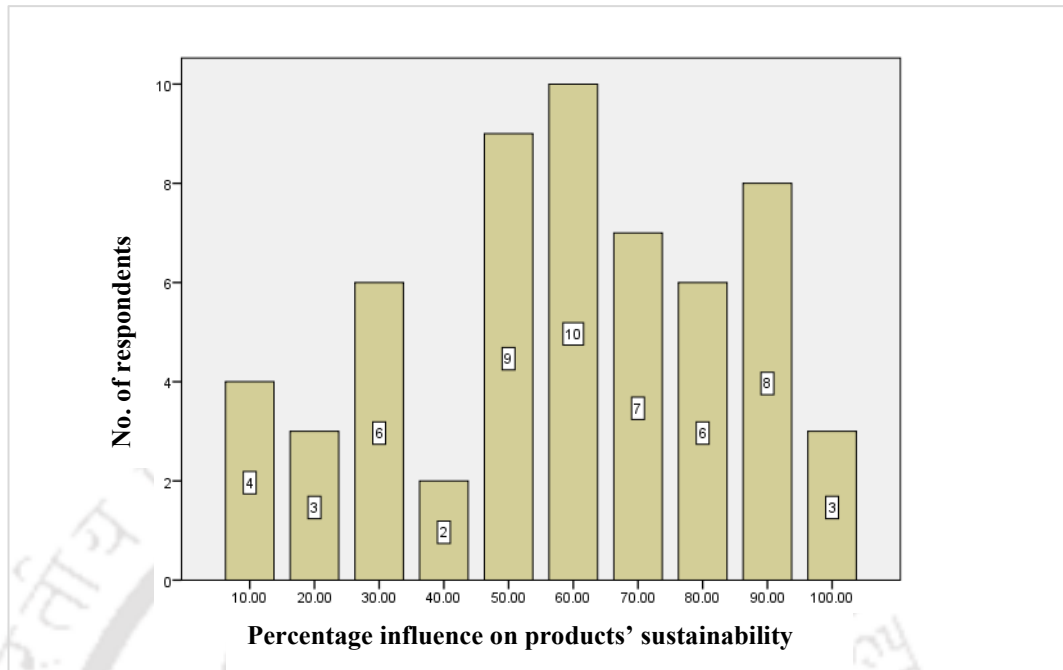


Figure 5-18: Influence of carbon footprint on products' sustainability (in %) according to respondents  
Source: Author-generated

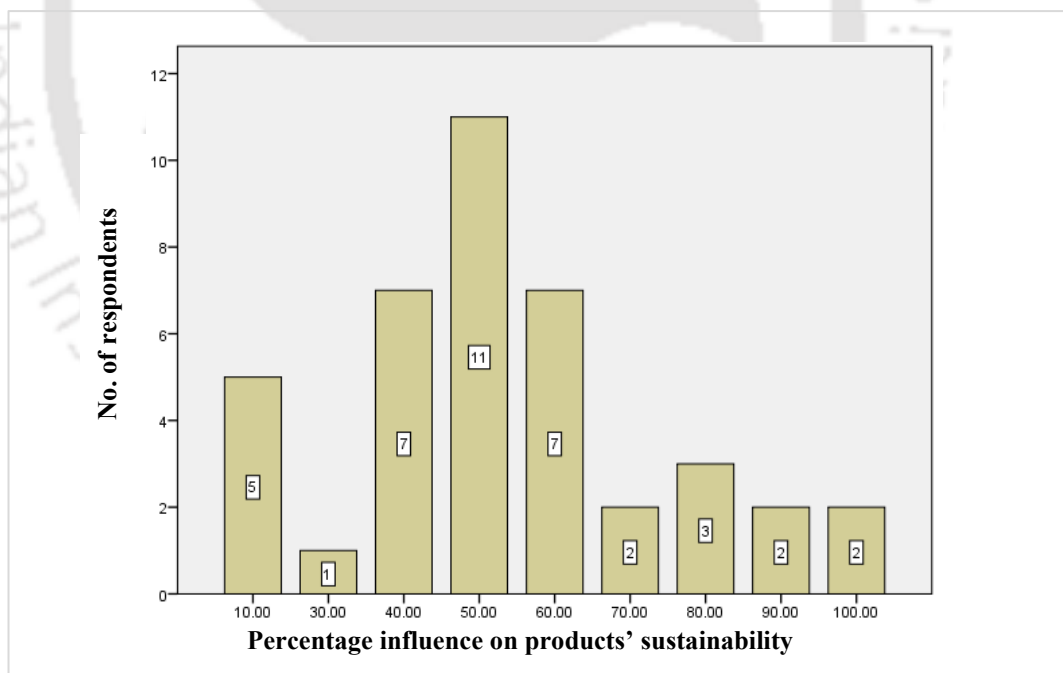


Figure 5-19: Influence of ecological footprint on products' sustainability (in %) according to respondents  
Source: Author-generated

*Carbon footprint:* Out of 70 participants, 58 showed their familiarity with this concept. Sixty-eight percent (40 out of 58) rated it within 50% to 90% (see Figure 5.18).

*Ecological footprint:* Out of 70 participants, only 40 showed their familiarity with ecological footprint out of which 62% (25 out of 40) rated it within 40% to 60% for influence on products' sustainability (see Figure 5.19).

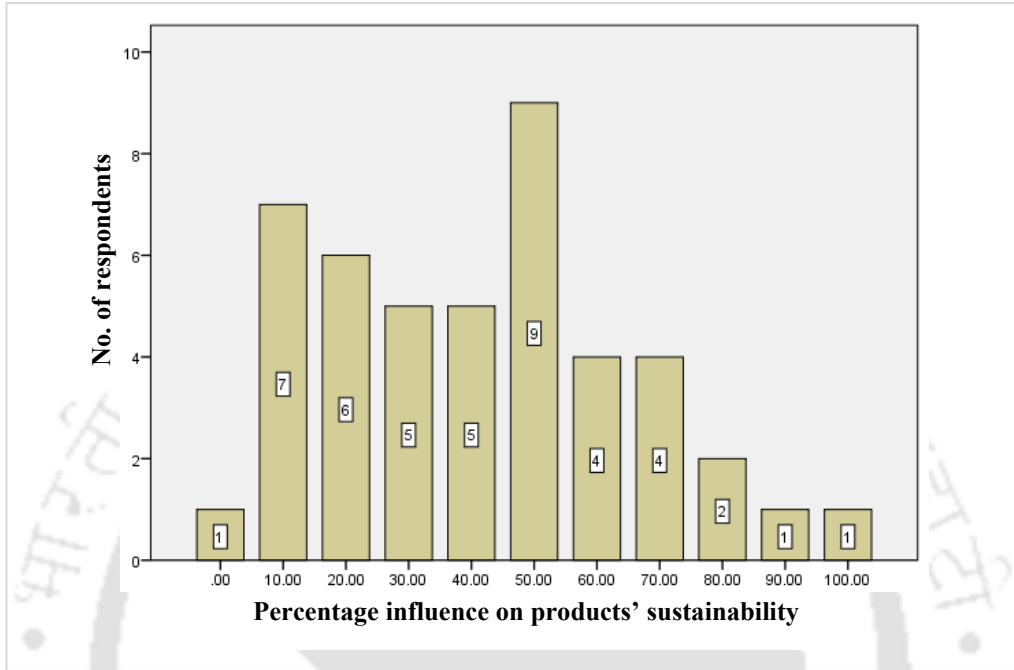


Figure 5-20: Influence of design for disassembly on products' sustainability (in %) according to respondents

Source: Author-generated

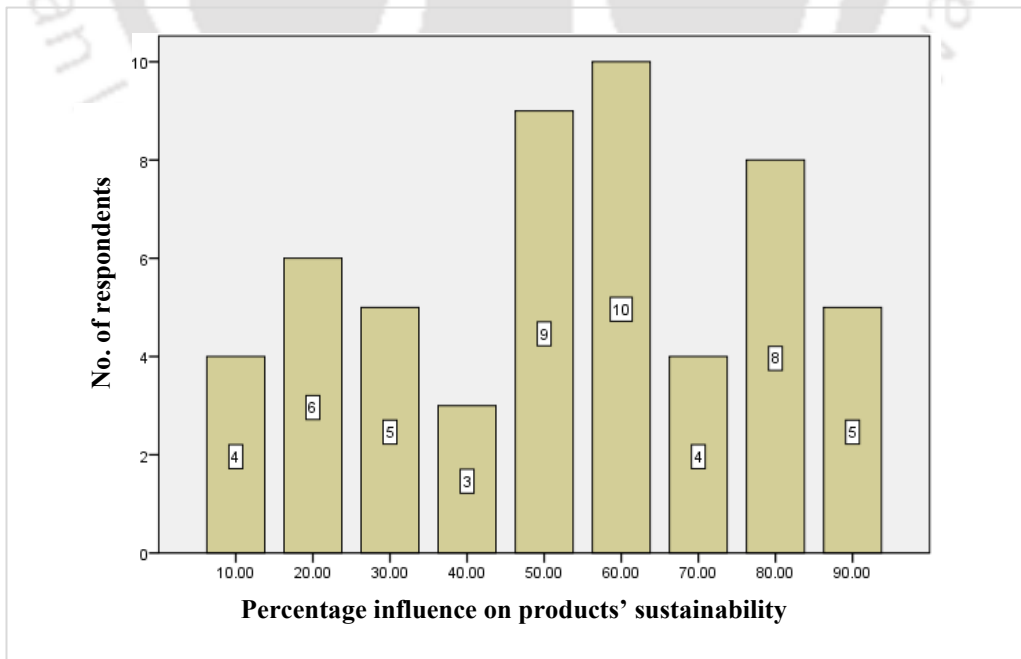


Figure 5-21: Influence of design for cleaner production on products' sustainability according to respondents

Source: Author-generated

*Design for Disassembly:* Out of 70 participants, 45 showed their familiarity with the concept and about 71% rated its influence on products' sustainability between 10 to 50 percent (see Figure 5.20).

*Design for Cleaner Production:* Fifty-five out of 70 participants reported their familiarity with this concept out of which 65% rated its influence on products' sustainability as 50% or higher (see Figure 5.21).

7. **Participants' self-evaluation of their knowledge of Sustainable Design (Q7):**

About 57% (40 out of 70) of the subjects evaluated themselves as 'beginners', whereas 21% (15 out of 70) assessed themselves as competent as shown in Figure 5.22 (Scale: 'novice', 'beginner', 'competent', 'proficient', 'expert').

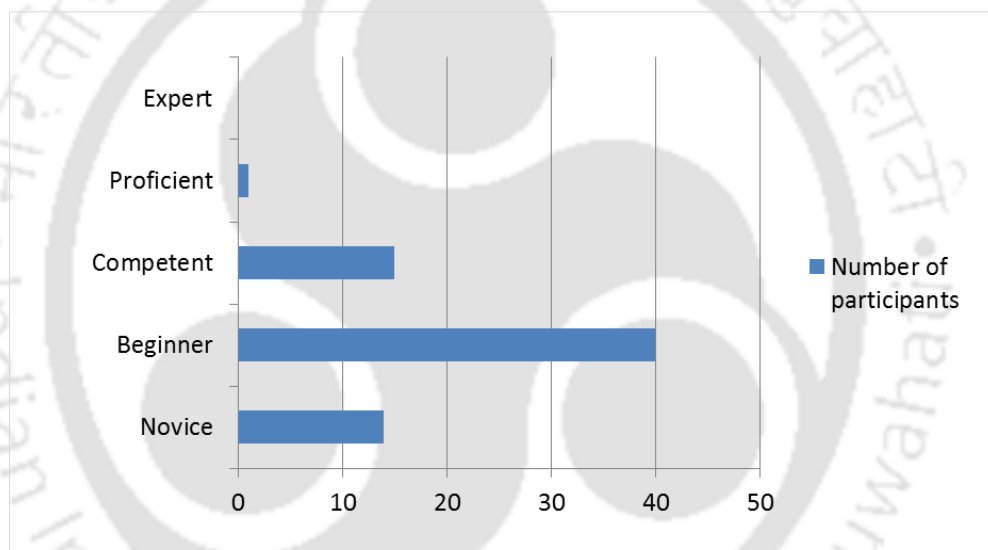


Figure 5-22: Self-evaluation of participants' about their knowledge of sustainable design  
Source: Author-generated

8. **Importance given to sustainability in relation to the rest of the design factors (subject's perception) (Q8):**

Designers need to consider many factors like ergonomics, aesthetics, function, manufacturing, etc. while designing. This question attempted to understand how important is sustainability as a parameter to the rest of the factors in participants' perception. Findings of the study showed that 47% of subjects felt that sustainability should be given an importance of 21–40%, whereas 23% estimated its importance as 41–60% (see Figure 5.23).

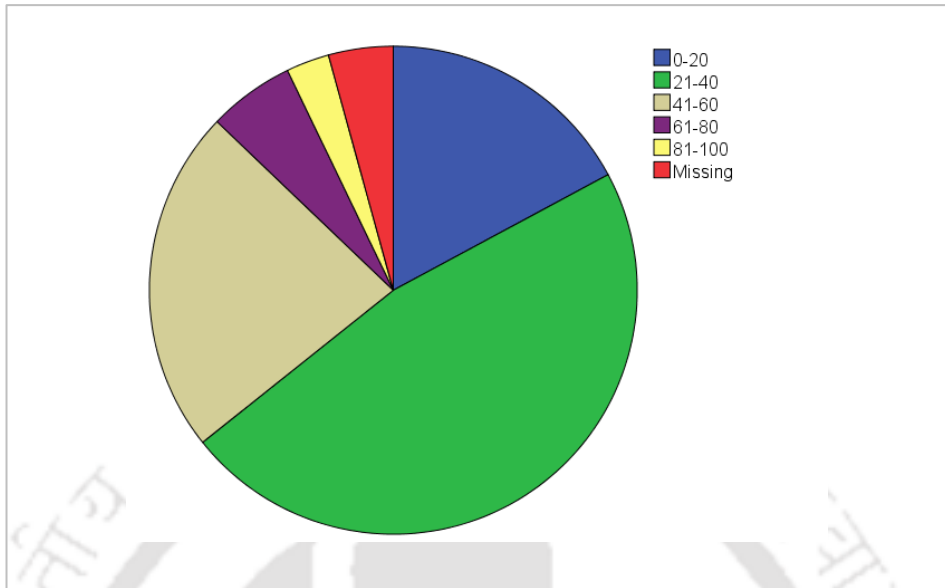


Figure 5-23: Participants' perception of importance given to sustainability compared to other design factors

Source: Author-generated

9. **Evaluation of their degree program (Q9):** About 36% (25 of 70) felt that their educational program offered input regarding sustainability 'somewhat', whereas 24% (17 of 70) assessed input as 'quite a bit'. Moreover, 24% (17 of 70) felt that their educational program was 'not at all' supportive, according to a scale with possible responses of 'not at all', 'somewhat', 'quite a bit', 'sufficient', and 'a great deal'.

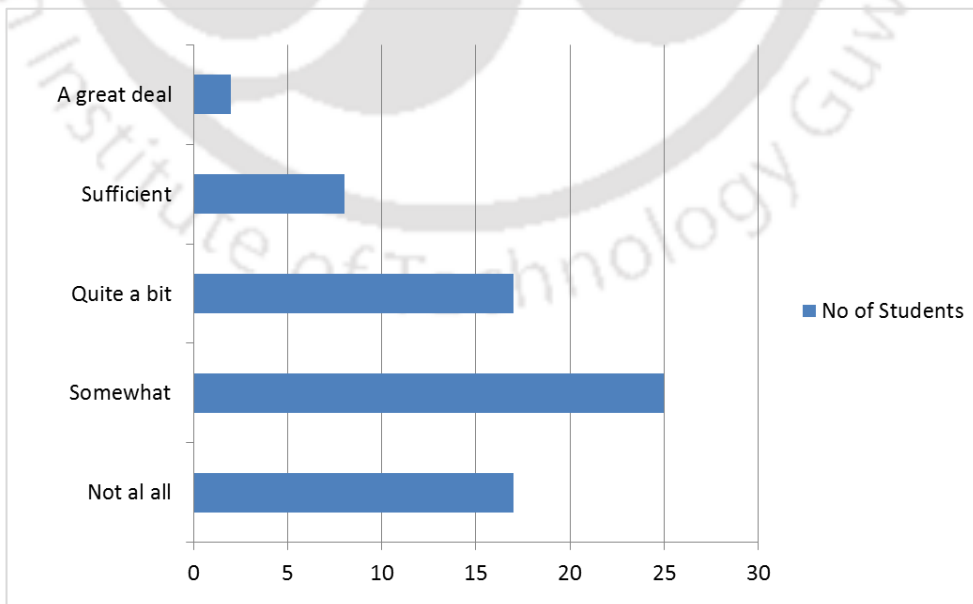


Figure 5-24: Participants' evaluation of their degree program for sustainable design inputs

Source: Author-generated

10. **Willingness to pay more for sustainable products (Q10, Q11):** More than 44% (31 of 70) of subjects responded that they were ‘sometimes’ willing to pay more for sustainable products, whereas 30 subjects said that they were willing to pay ‘often’ for such items (see Figure 5.25). None of the respondents said that they are never willing to pay more for sustainable products (Scale: ‘never’, ‘sometimes’, ‘often’, ‘always’, ‘not sure’). However, when asked to recall the last sustainable products bought by them, 28% could not recall. The most common products mentioned by them were Jute bags, recycle paper notebook, paper bags, CFL lamps, Apple MacBook Pro, tetra packs.

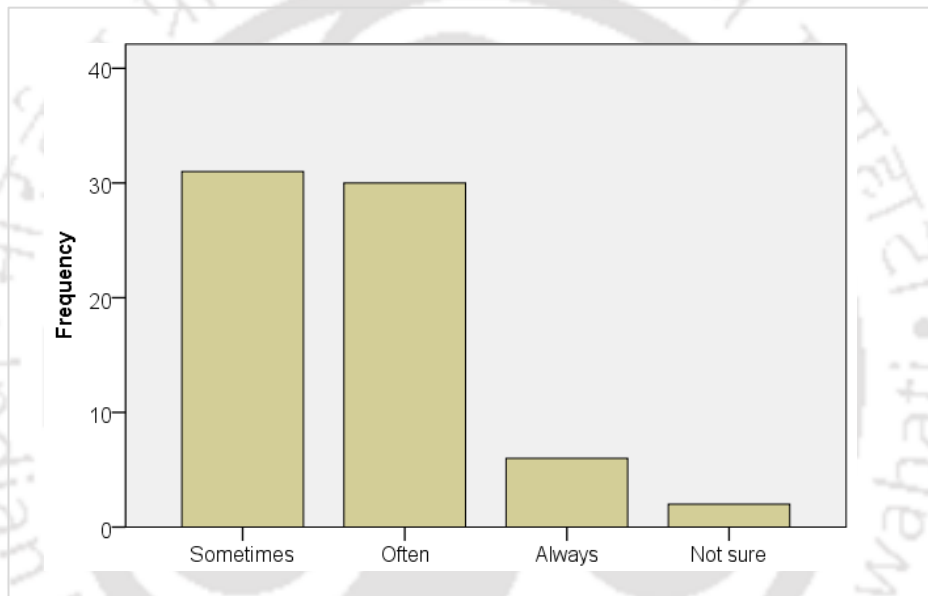


Figure 5-25: Willingness of participants to pay more for sustainable products

Source: Author-generated

11. **Perception about sustainability of products (Q12):** Subjects were shown three products (bio-degradable milk packaging, reusable shirt packaging, and Tata Nano car) and were asked to rate its sustainability on a scale of 1 to 10 where, 1 means ‘unsustainable’ and 10 means ‘ideally sustainable’.

*Bio-degradable milk packaging:* Out of 70 participants 57 responded to the question, and 56% (32 of 57) rated it 6 to 7 on sustainability scale (see Figure 5.26).

*Reusable shirt packaging:* Fifty-seven participants responded to the question and about 71% rated it 7 to 9 on sustainability scale (see Figure 5.27).

*Tata Nano car:* Fifty-six participants responded to the question out of which 58% (33 of 57) rated this product 4 to 6 on sustainability scale (see Figure 5.28).

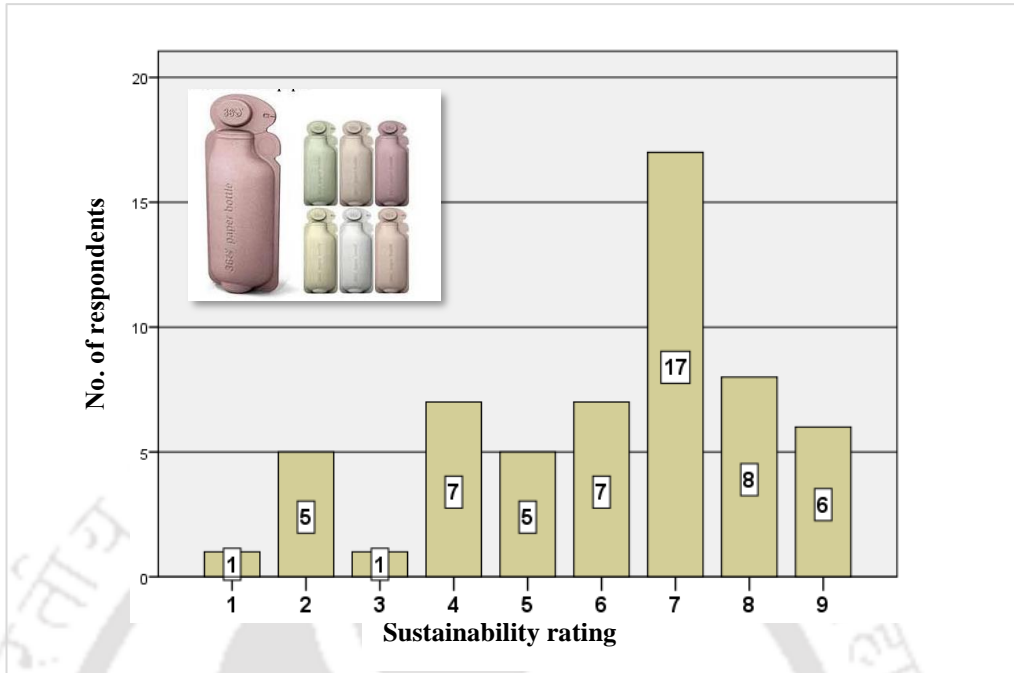


Figure 5-26: Sustainability rating of bio-degradable milk packaging by participants

Source: Author-generated

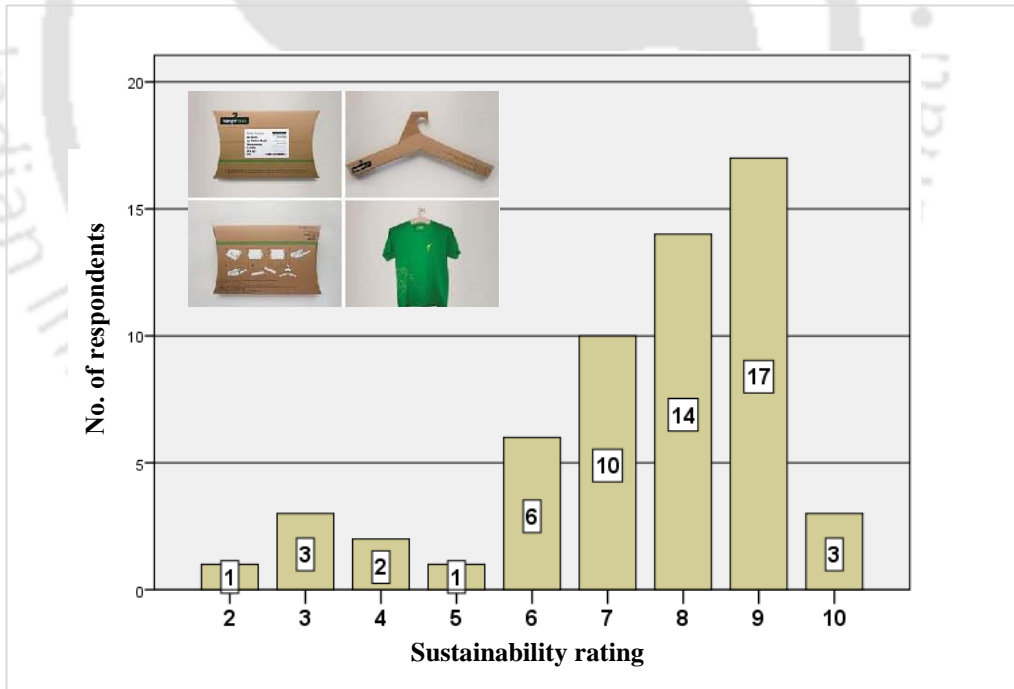


Figure 5-27: Sustainability rating of reusable shirt packaging by participants

Source: Author-generated

It can be observed that most of the subjects rated the first two products high (6 to 8) whereas for the last product it was rated lower (4-6). One of the possible explanations for this observation may be the participants' perception of sustainability that recognises bio-

degradability and reusability as important conditions for sustainability. In the case of Nano car no such popular association was seen and thus was rated low. The complexity of the product is also likely to have an effect on rating the products. It's easy to comprehend the sustainability affecting parameters of a simpler product but becomes a difficult task for complex products like a car.

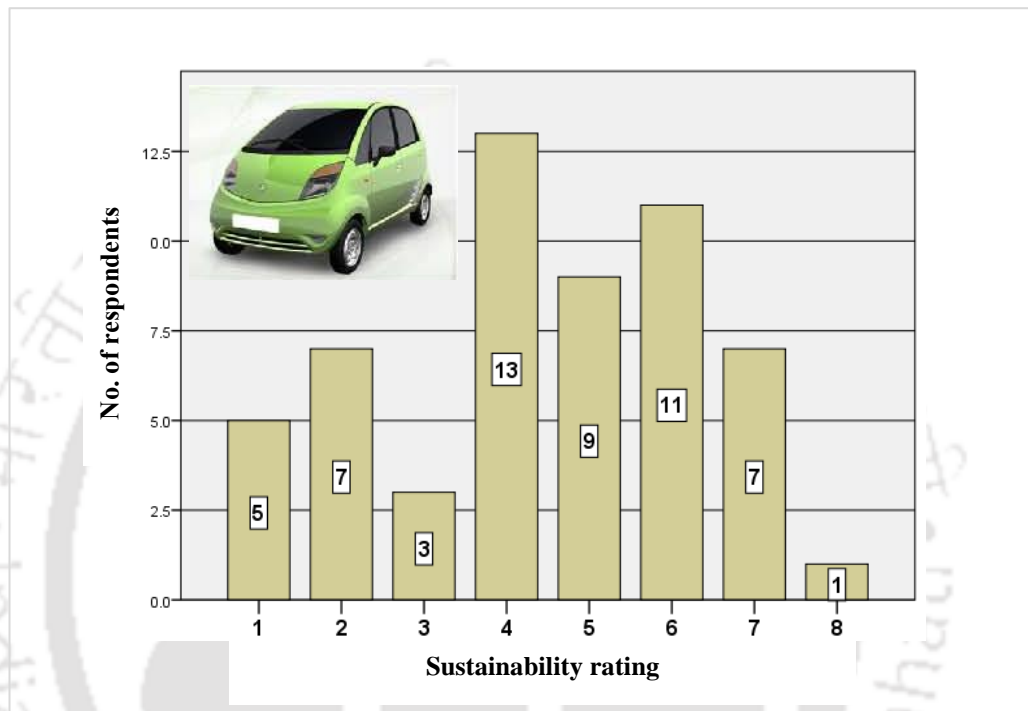


Figure 5-28: Sustainability rating of Tata Nano car by participants

Source: Author-generated

### 5.3.2. Analysis - Section 2

This section first presents the method of analysis used for section 2 of the empirical study and then it discusses the results of the analysis. Section 2 of the instrument was a problem-solving exercise already discussed in Section 5.2.3.2 (page 84). The main method of analysis adopted for this section was content analysis.

#### 5.3.2.1. Method of Analysis

Content analysis was used as a method for drawing inferences from section 2. At first, the response sheets and sketches were studied and then content was extracted under following headings.

1. *Methodology Shown*: Content regarding the overall methodology followed by the subjects while solving the given design problem.

2. *Sustainability variables*: Factors/variables that were pointed out by the subject while solving the problem. It also includes the variables populated in the fill-up sheet provided (refer Section 5.2.3.2, page 84).
3. *Methods used*: it included various methods that were used by the participants while solving the given problem.

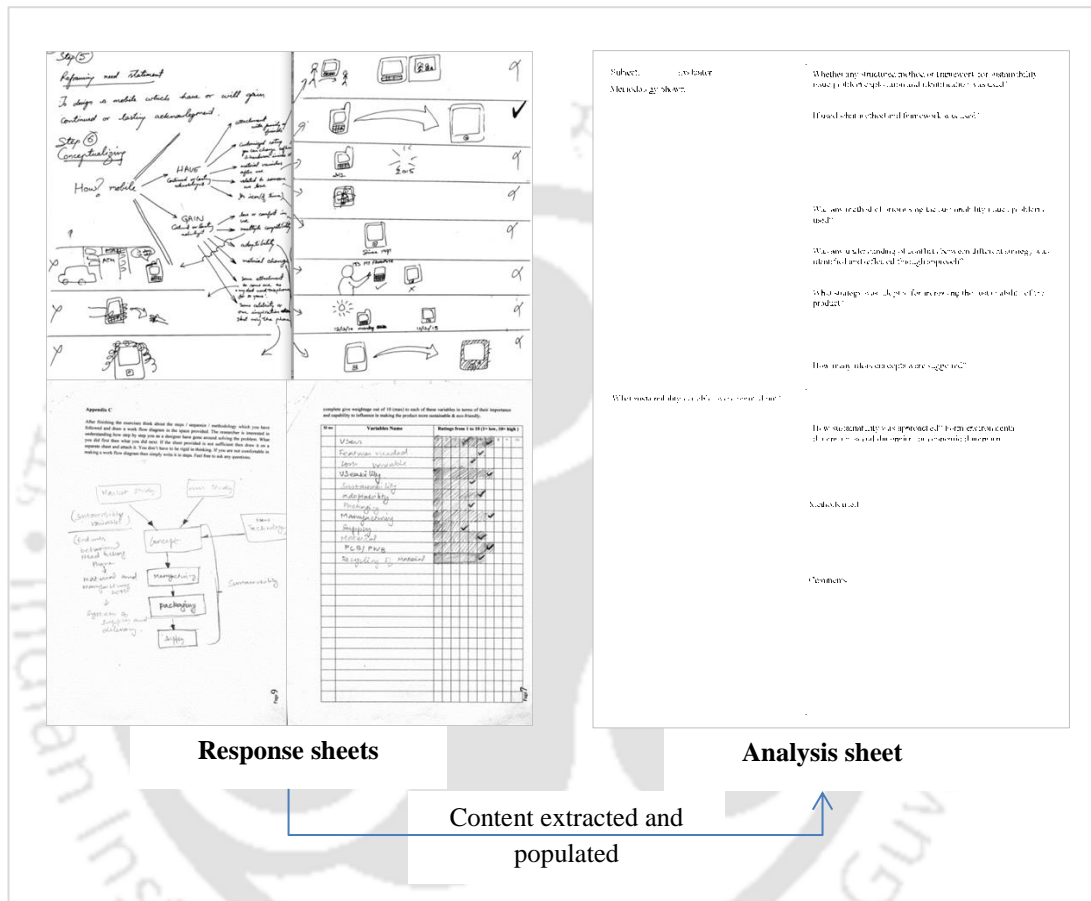


Figure 5-29: Data entry procedure for Section 2 of the instrument

Source: Author-generated

Apart from the content regarding the headers mentioned above, following questions were also explored.

1. Whether any structured method or framework for sustainability issue/problem, exploration and identification were used? If used what method and framework?
2. Was any method of prioritising the sustainability issues/problems used?
3. Was any understanding of conflicts between different sustainability issues identified by the participants and reflected through their approaches?
4. What were the different strategies adopted by the participants for increasing the sustainability of the product?

- How was sustainability approached? From environmental dimension, social dimension, or economic dimension?

A coding sheet was prepared, and contents were populated based on the above headers and questions (see Appendix 3). Figure 5.29 illustrates this process of data entry.

### 5.3.2.2. Result of Analysis

Following were the results of content analysis populated in the coding sheet.

- Methodology Shown:* Four broad approaches were observed from the study of the methodology followed by the subjects. These four approaches were labelled type 1 to type 4 and are discussed in the following sections. Table 5-2 illustrates subject-wise list according to the observed methodology (see Appendix 4 for details on steps followed by the participants).

Table 5-2: Subject-wise distribution of methodology shown  
Source: Author-generated

| Methodology followed | List of participants   | Total number of participants |
|----------------------|--|------------------------------|
| Type 1               | A9   | 1                            |
| Type 2               | A11, A12, A21, A23, A35, B64, A14                                    | 7                            |
| Type 3               | A13, A15, A19, A24, B45, B48, B52, B53, B55, B58, B60, B63, B65, C70 | 14                           |
| Type 4               | A20, B36   | 2                            |

**Type-1 methodology:** Type 1 methodology strongly resembles the traditional model of the design process (as illustrated in figure 2.4, page 27) and was observed in only one subject’s response sheet. Figure 5.30 illustrates a comparison between the descriptive model of the design process and the methodology drawn by the subject.

**Type-2 methodology:** Seven out of 24 showed a diversion from the traditional morphology of design (as illustrated in figure 2.4, page 27) and was labelled type-2. In this, the subject started with the steps prescribed in traditional design morphology, but later added steps for exploration of sustainability issues using methods like lifecycle analysis, heuristics, etc. Figure 5.31 highlighted the methodology drawn by two subjects along with added steps for sustainability.

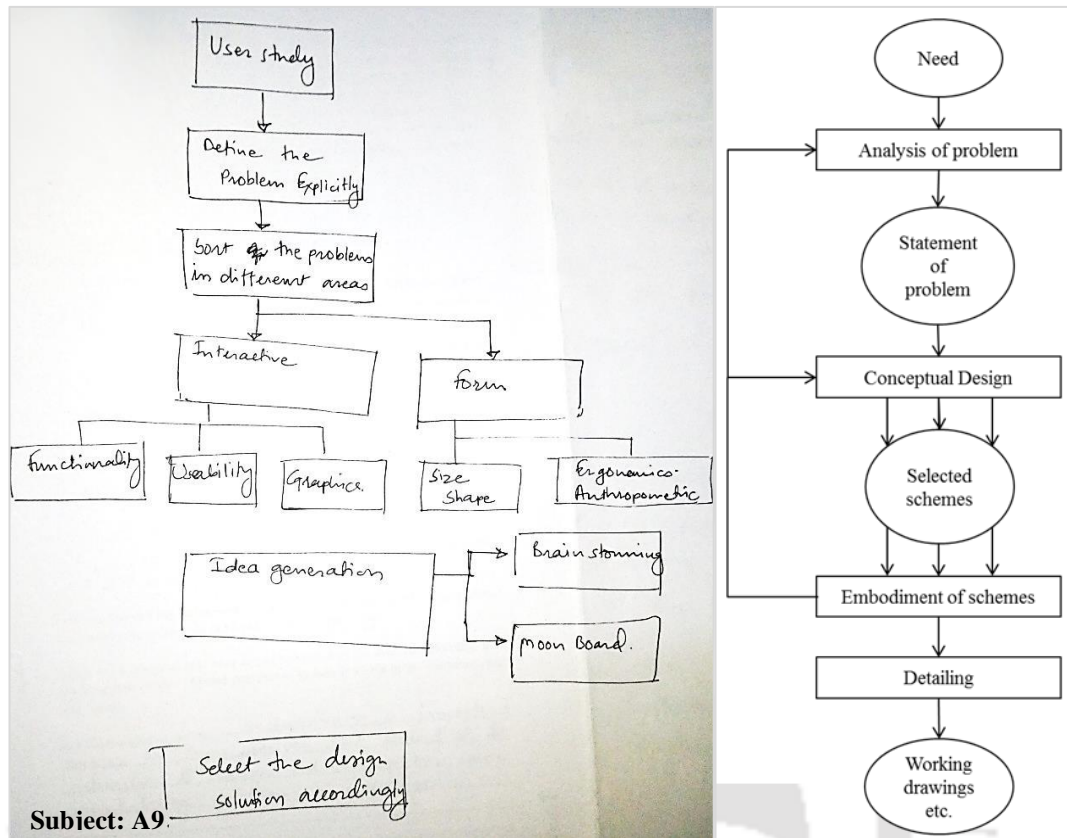


Figure 5-30: Type 1 methodology shown by subjects in comparison with traditional design process  
 Source: Respondent methodology against design methodology of French (1999)

**Type-3 methodology:** This approach was observed in most of the participants' (14 out of 24) response sheets. The subject at first started with an exploration of sustainability philosophy and its implications for the given task and then went on generating concepts as per traditional design morphology. The subjects showed different methods of exploration like triple-bottom-line model, lifecycle analysis, etc. Figure 5.32 shows the response sheet of two such subjects as an example.

**Type-4 methodology:** This approach was observed in two subjects' response sheets. These subjects directly started with conceptual sketches and did not show any structured model or process of design. These subjects are likely to show the black-box model of problem solving (see Figure 5.33).

As far as type-1 and type-4 subjects were concerned, it was difficult to interpret their way of approaching sustainability while designing. However, two important observations were made from the response sheets of subjects that used methodology labelled as type-2 and type-3. They are as follows:

- a. The first observation was that all 21 subjects (out of 24) added extra steps to their morphology for exploring sustainability and its implications for the given problem. These steps were added at two different points of their morphology. Seven added it as a second step after need/problem/user definition, and 14 as their first step.
- b. The second observation was that the methodology illustrated by all 21 subjects shows correspondences with the traditional design morphology.

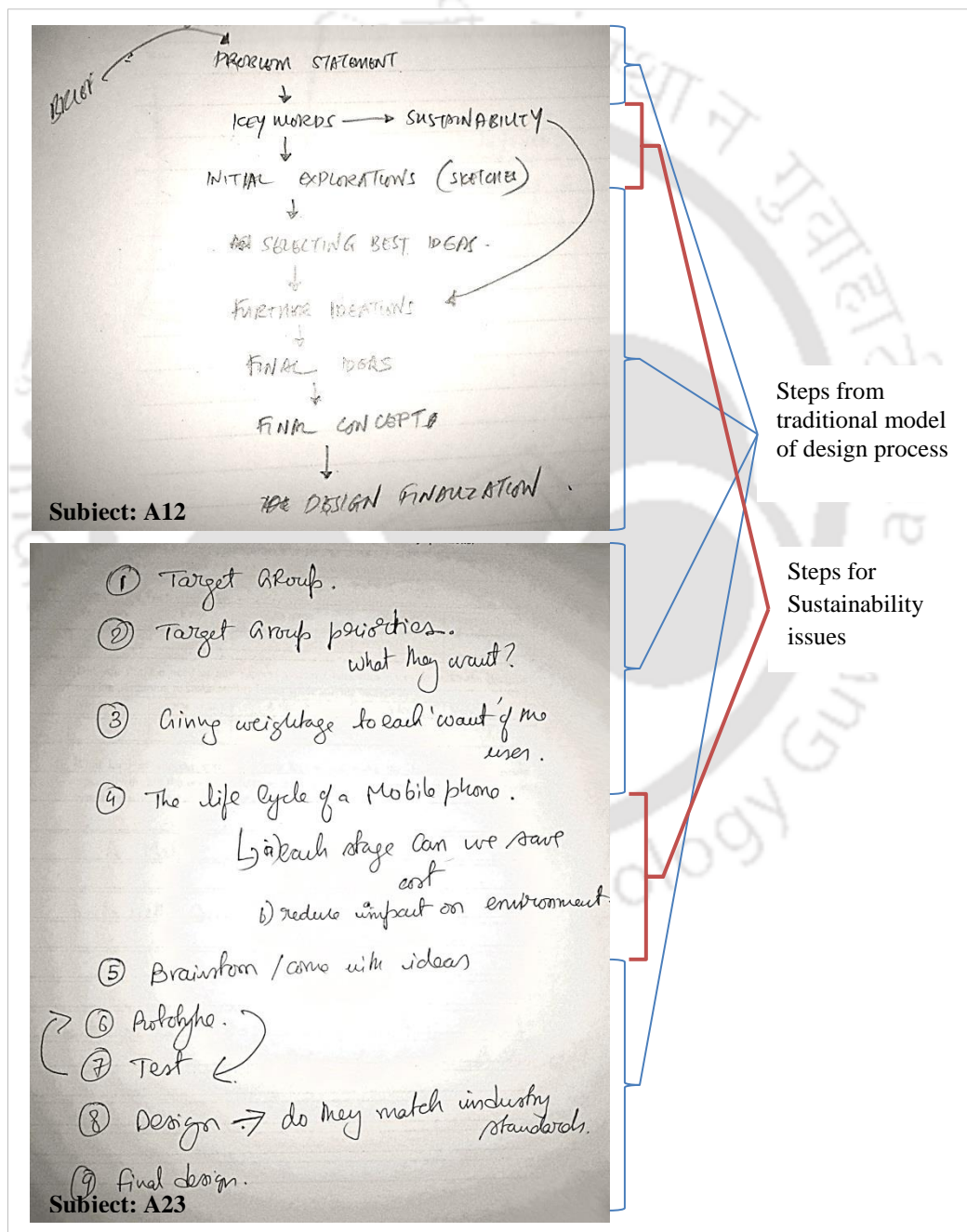


Figure 5-31: Examples of Type 2 methodology

Source: Respondent-generated

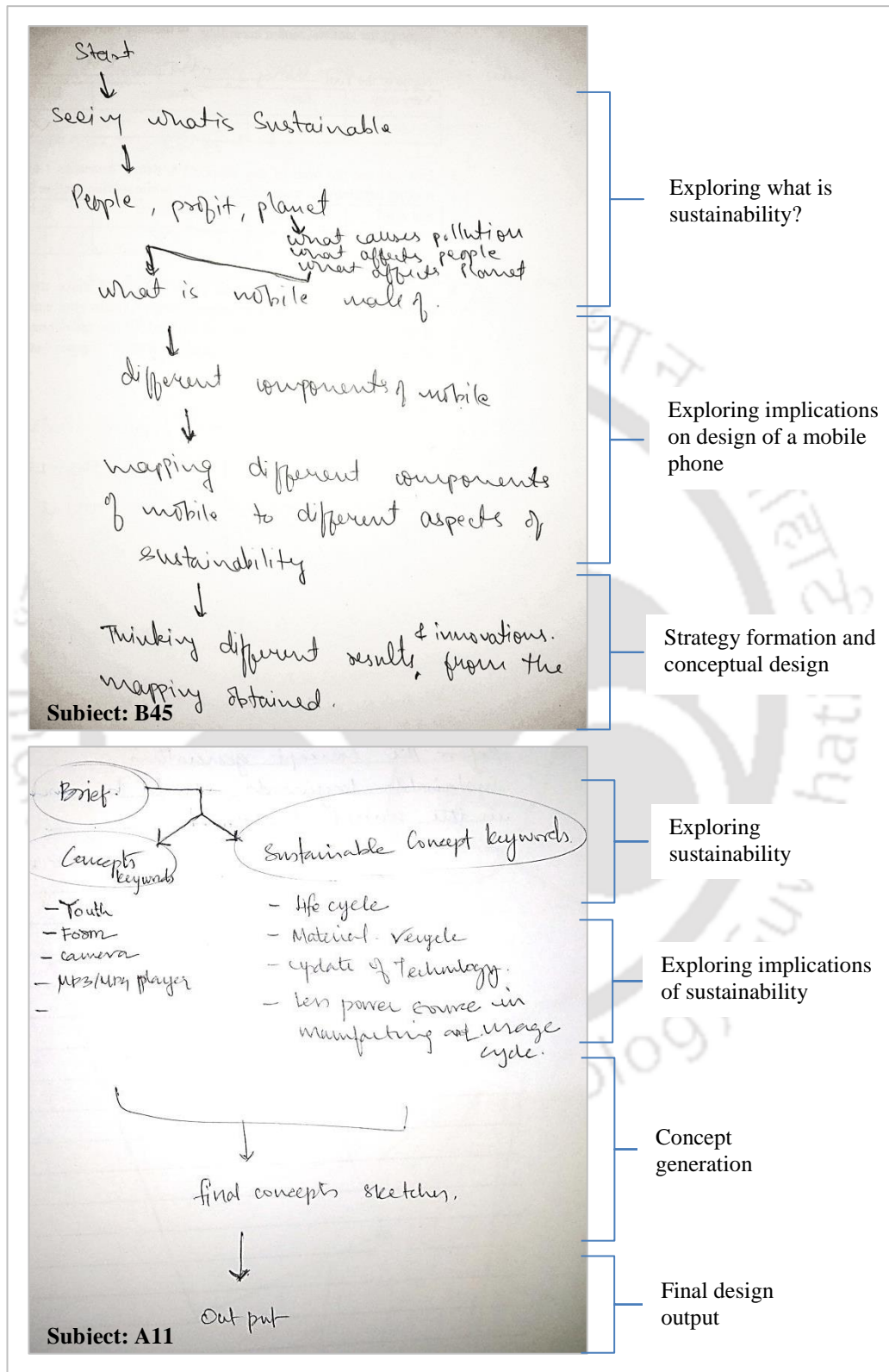


Figure 5-32: Examples of type 3 methodology observed

Source: Respondent-generated

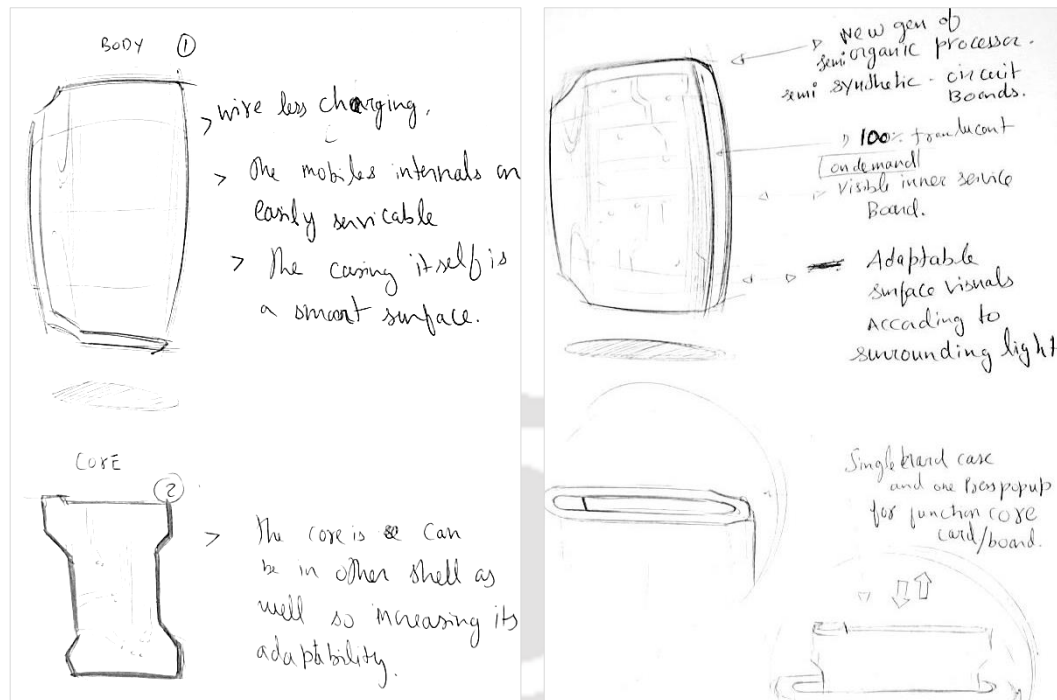


Figure 5-33: Examples of type 4 methodology observed

Source: Respondent-generated

Refer Appendix 4 for a complete list of the methodology followed by each respondent. Appendix 5 presents the thumbnail screenshots of the response sheets illustrating the methodology followed by all the respondents.

2. *The method of exploring sustainability issues illustrated by participants:* Out of 24 respondents, 21 (type-2 and type-3) demonstrated one or more ways of exploring and identifying sustainability issues. Three types of approaches were observed for sustainability explorations that were labelled as 'random', 'semi-structured' and 'structured'. Nine subjects' approach towards exploring sustainability issues were observed to be random where either they used some heuristics like material reduction, biodegradable material use, etc. or listed down some variables related to sustainability like material, energy, toxicity, etc. These subjects were labelled as 'random'. Seven subjects' exploration approach was labelled as semi-structured as they mentioned approaches like product lifecycle, mind mapping for unsustainability but did not use it. Five subjects' exploration approach was found to be structured as they both used methods like fish-bone diagram; lifecycle mapping etc. or the triple bottom-line framework and used it to relate it to the problem given to them. Table 5-3 illustrates approach-wise classification of participants and the methods used.

Table 5-3: Method of sustainability exploration adopted by subjects (type-2 and type-3)

Source: Author-generated

| Approach        | List of Subjects                            | Methods and frameworks used  |
|-----------------|---|--|
| Random          | A11, A12, A13, A14, A24, B53, B58, B63, B64 | Sustainability keywords<br>Heuristics for sustainability<br>Sustainability variable listing  |
| Semi-structured | A21, A23, B48, B52, B55, B65, C70           | Product lifecycle, mind-mapping, mapping why mobile phone is not sustainable   |
| Structured      | A15, A19, A35, B45, B60                     | Mind mapping, Fishbone diagram, Product component Mapping, Brainstorming using product lifecycle, Triple-bottom-line mapping with mobile phone component, triple-bottom-line framework |

3. *Prioritising identified sustainability issues*: No observation was made in response sheets of any participants which reflects their attempted to prioritise the identified sustainability issues.

4. *Conflicts between sustainability issues*: No observation was made in the respondent's response sheet that reflects that they were aware of the conflicting nature of identified sustainability issues.

Table 5-4: Suggestion of subjects for increasing the sustainability of mobile phones

Source: Author-generated

| Sustainability dimension | Suggestions  |
|--------------------------|--|
| Environment              | Reusable material, reduce materials, packaging-jute bags, reuse of parts, sustainable disposal, Upgradability through modular structure, Serviceable parts, , material suitable for disposal, strong, , recyclable, renewability of materials, optimised, software- upgradability, optimise battery use, work with low-end hardware, disassembly, packaging, fewer parts, colour, reduce manufacturing cost, strong and durable, recyclable battery, use biodegradable plastic recycle – reuse –reduce, reuse of discarded phone durability, eco-friendly, less toxic production, software – energy saving, tone vibration, security |
| Social                   | Design for bottom of the pyramid, extension of life through emotional attachment, easy cover replacement, promote recycling, ease of use, providing numerous functions, low radiation, usability, modify user behaviour, persuade to buy eco-friendly products, emotional appeal   |
| Economy                  | pricing  |

5. *Sustainability dimensions discussed*: Most of the subjects (13 out of 21) explored only the environmental dimension of sustainability, whereas four subjects discussed issues about social dimension only. Three participants discussed both environmental

and social dimension, and only one subject discussed all the three dimensions of sustainability. Table 5-4 illustrates the strategy suggested by 21 subjects for making the product more sustainable.

## 5.4. Observations and Inferences from Analysis

This section presents the observation and inferences drawn from the results of the analysis presented in the previous section 5.3.1.2 (page 88) and 5.3.2.2 (page 104)

### 5.4.1. Observations and Inferences: Section-1

Following were the main observations and inferences from the analysis and results of Section 1 discussed in Section 5.3.1.2 (page 92).

1. Subjects who participated in the survey were found to have limited exposure to sustainability education through formal means (see Section 5.3.1.2, point 3, page 93). It indicates a lack of sustainability integration with the design program of the surveyed institution. However, there is a raising awareness towards sustainability in Indian design schools which was reflected by the number of subjects (more than 50%) participating in sustainability related conferences/ seminars/workshops (see Section 5.3.1.2, point 4, page 94). Considering this trend is prevalent in other design institutions of India one can infer that although there a growing concern towards sustainability education, it has not yet been integrated with the design programs.
2. The self-evaluation of the participants about their knowledge of sustainable design reflected that most of the subjects (57%) consider themselves as a beginner on a five-point scale (novice-beginner-competent-proficient-expert). Only 21% assessed them as competent or proficient (see Section 5.3.1.2, point 7, page 102). Moreover, 60% of the participants evaluated their degree program to be either 'not at all supportive' or 'somewhat supportive' for sustainable design inputs (see Section 5.3.1.2, point 9, page 103). These two observations also reflect a lack of formal sustainability education in the surveyed design schools.
3. Nearly 47% participants perceive that sustainability factors should be given 21-40% importance compared to other design factors whereas 23% gave it the importance of 41-60% (see Section 5.3.1.2, point 8, page 102). When asked about their willingness to pay more for a product that is labelled sustainable, 44% of the subjects told that they are 'sometimes' willing to pay more whereas, 40% told that they are 'often'

ready to pay more (see Section 5.3.1.2, point 10, page 104). These results are also indicative of growing concern about sustainability issues and their positive attitude towards it.

4. The content analysis of sustainability definitions given by subjects from various perspectives showed a bias towards the environmental dimension (see Section 5.3.1.2, point 5, page 94). Most of the subjects' definition of sustainability was closer to the concept of eco-design and showed a resource conservationist approach towards approaching sustainability. While rating the influence of various concepts like green design, eco-design, design for the environment etc. on products' sustainability a lack of inter-relationship understanding was observed. For example 66% of the subjects perceive that green design has 60% or more influence on products' sustainability whereas 70% of the subject rated the influence of eco-design on products' sustainability more than 60% (see Section 5.3.1.2, point 6, page 96). These results reflect that they perceive sustainable design closer to the environmental-conscious concepts of green design and eco-design.
5. When rating the three example products the subjects identified bio-degradability and reusability as important parameters of a sustainable product and rated such products (bio-degradable milk packaging and reusable shirt packaging) higher on the scale whereas, for a complex product (like Tata Nano car), where such attributes were not clearly identifiable was rated low (see section 5.3.1.2, point 11, page 104). It also reflects their understanding of a sustainable product to be something that is biodegradable, reusable, etc. which are mainly concerned with environmental sustainability.

#### 5.4.2. Observations and Inferences: Section - 2

Following were the main observations and inferences from the analysis and results of Section 2 discussed in Section 5.3.2.2.

1. Four broad methodological approaches were observed in the response sheets of subjects. Most of them (21 out of 24) showed a methodology which was a diversion from the traditional design morphology as they added extra steps for sustainability exploration (see Section 5.3.2.2, point 1, page 108). It reflects their adherence to the methodological way of designing that is very popular in design schools for imparting design education.

2. The extra step of sustainability exploration was found to be either random or semi-structured in 76% of the subjects' response sheet (see Section 5.3.2.2, point 2, page 112). The most common method of sustainability exploration was product lifecycle, triple-bottom-line model of sustainable development and mind mapping. However, most of their explorations were focussed on the environmental dimension of sustainability (see Section 5.3.2.2, point 5, page 113). These observations reflect participants' biased mental model towards environmental dimension and a lack of structured approach towards sustainability exploration. It also indicates that the participants felt difficulty in building a relationship between sustainability as a concept and the problem at hand.
3. No observations were made regarding their way of prioritising the sustainability issues identified by the subjects (see Section 5.3.2.2, point 3, page 113). Moreover, no observation was made which could reflect their understanding of the conflicting behaviour of sustainability dimensions and their issues (see Section 5.3.2.2, point 4, page 113). Prioritising the sustainability issues and understanding the conflicts between the sustainability dimensions is very critical in solving sustainable design problems. A lack of which may not result in an efficient solution.
4. From the above observations, it can be inferred that the traditional design morphology in sustainable design context has limited scope.

## 5.5. Verifying the Working Posits

Two working posits were put forward concerning RQ2 and RQ3 (page 46) in the empirical study reported in this chapter.

**P1** posited that the 'existing perceptions and mental models of creative designers about the concept of sustainable design is biased towards the environmental dimension of sustainability'.

The observation and inferences drawn in section 5.4.1, point 4 (page 115), section 5.4.1, point 5 (page 115) and section 5.4.2, point 2 (page 114) supports our position P1 under this study.

**P2** posited that the 'existing morphological 'approach' of novice creative designer to sustainability given a sustainable design problem is through the environmental dimension'.

The observation and inferences are drawn in section 5.4.2, point 2 (page 116), reflected that most of the sustainability exploration, issue identification was dominated by environmental dimensions. It supports our posit P2 under this study.

## 5.6. Conclusion

This chapter was focussed on the second research gap identified in section 2.6.2 (page 48) concerning a lack of studies towards exploring mental models and problem-solving approaches of creative designers in the context of sustainable design. It attempted to answer RQ2 and RQ3 (page 16) (and achieve OB2 and OB3) through an empirical study.

This study indicated that despite the broadening of scope in literature from green design to sustainable design (as shown in Chapter 2), the mental models of novice designers about sustainable design are still limited to the environmental concerns, and lacks a comprehensive understanding. They perceive environmental-conscious concepts like eco-design and design for the environment as sustainable design. Given a sustainable design problem, most subjects the problem through environmental dimension and a lack of understanding about the other dimensions of sustainability was observed.

The methodological way of designing that is considered one of the most important methods of imparting design education dominated the problem-solving approaches of the novice designers in the context of sustainable design. However, to incorporate sustainability, extra steps were added to the traditional morphology of design. It indicated that the traditional morphology of design finds limited use in approaching a sustainable design problem, and there is a need of improved morphology.

These observations necessitate the need of a design morphology that incorporates the sustainability consideration within. Such morphology is expected to improve the understanding of design students while in design training. Imparting sustainability education through integrated sustainability design morphology holds tremendous potential towards sustainability education. The following chapter proposes a method of developing such an integrated sustainable design morphology based on the framework proposed in Chapter 4 and the inferences drawn from this chapter.

## Chapter 6

(Phase 3)

# Towards Developing a Model of Sustainable Design Morphology

This chapter focuses on the third research gap identified in section 2.6.3 (page 45); concerning RQ4 and OB4 (page 16). The chapter intends to propose a model of sustainable design morphology for novice creative designers based on the findings of chapter 4 and chapter 5. Chapter 4 proposed a comprehensive framework for sustainable design with ten directions of sustainability. The empirical study reported in chapter 5 indicated that novice creative designers lack a comprehensive understanding of sustainability, and their perceptions and mental model are biased towards environmental dimension. Moreover, it was indicated that their problem-solving approach to sustainable design corresponds with traditional design morphology. The popular models of design processing steps (design morphology) presented in literature did not give any guidance regarding incorporation of sustainability issues and finds limited use for novice designers in designing for sustainability. These two observations necessitated the need of design morphology for sustainable design, which can guide novice creative designers in incorporating sustainability issues comprehensively.

## 6.1. Introduction

The understanding of the multidimensional nature of sustainable design philosophy is very crucial for creative designers in conceptualising sustainable products. However, its historical precedence (i.e. green design and eco-design) and close correspondence with sustainable development philosophy has resulted in a varied and partial understanding of the philosophy. This diversity of understating has already been discussed in Chapter 2, Section 2.4 (page 34). To comprehend this diversity, Chapter 4 derived ten directions of sustainability as a framework for sustainable design.

Chapter 5 reported the empirical study conducted to explore novice designers' perceptions, mental models and problem-solving approaches towards sustainable design. The study indicated that the perceptions and mental models of novice designers were biased towards the environmental dimension of sustainability. Moreover, their approach to problem solving (given a sustainable design problem) did not cover the dimensions comprehensively. It was also observed that most participants adopted a methodological approach to problem solving which closely corresponded with the traditional design morphology (as shown in figure 2.4, page 27).

It has already been pointed out in Section 2.2.1 (page 26) that design morphology is among the most popular method of imparting design education and is highly recommended in design literature (Radcliffe & Lee, 1989; Pahl and Beitz, 1999; Howard, Culley and Dekoninck, 2008; Nigel Cross, 2008; Eder & Hosnedl, 2010). Design morphology is also considered an efficient way of managing design projects, especially for novice designers. However, these morphologies do not provide any inputs regarding sustainability issues and was found to be of limited use in the context of sustainable design (as observed in empirical study of chapter 5, section 5.4.2, page 115).

This chapter intends to propose a model of sustainable design morphology by integrating the directions of sustainability derived in Chapter 4, with the creative phase of design. The creative phase of design has already been shown to be very critical from a sustainable design perspective, as discussed in Section 1.2.4 (page 10). Such morphology is expected to have a great potential towards imparting sustainability education to novice designers. On one hand it is expected to assist creative designers (especially novice designers) in incorporating sustainability features in their designs, while on the other hand

expected to help them in understanding the comprehensive nature of sustainability and remove their bias towards environmental dimension.

At first, the following section recapitulates the stages of creative design and highlights on the major activities involved in those stages. Then section 6.3 proposes a model of sustainable design morphology by integrating the corresponding sustainable design activities (derived in Section 6.3.1) with the activities of traditional design morphology.

## 6.2. Recapitulating Activities of Design Morphology

The comparative analysis of 27 different design morphologies revealed that the most common phases of design process are ‘analysis of task’, ‘conceptual design’, ‘embodiment design’ and ‘detailed design’ (Howard et al., 2008). Apart from these four phases ‘establishing the need’ (preceding ‘analysis of task’) and ‘implementation phase’ (followed by ‘detailed design’) were additional in few cases (Howard et al., 2008). These phases have been illustrated in Figure 6.1.

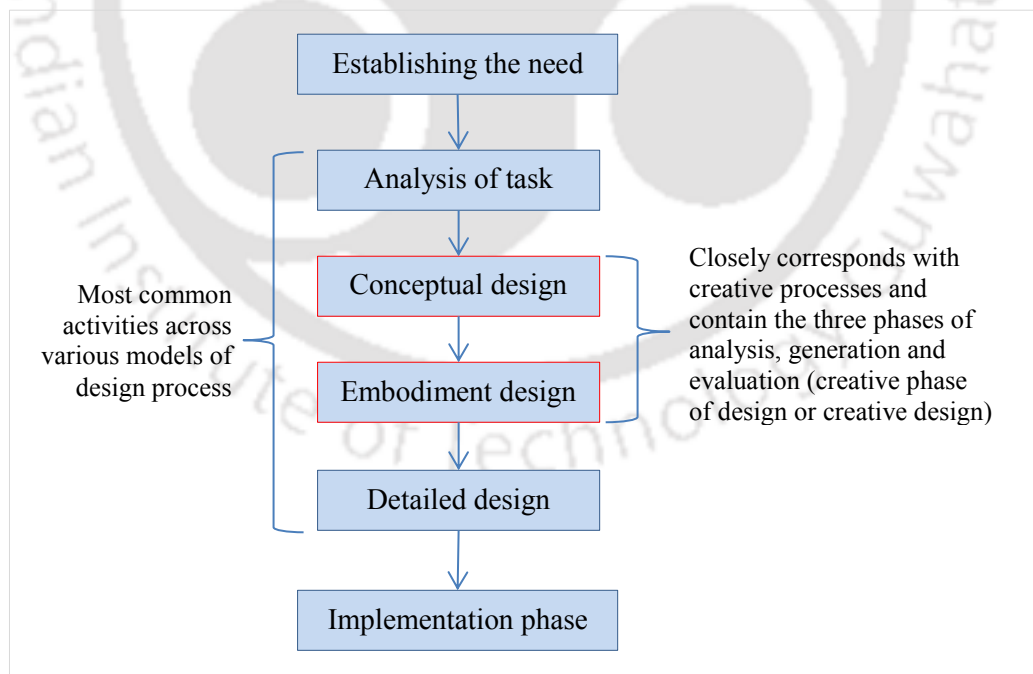


Figure 6-1: Common activities across different models of design process

Source: Adapted from (Howard et al., 2008)

It was also observed that the conceptual design and embodiment design phase put together closely corresponds with creative processes consisting of three iterative phases

of analysis, synthesis and evaluation. This is the reason this part of design morphology is often referred as creative design phase. The most common activities in this phase of design have been enlisted in Table 6-1 (see Chapter 2, Section 2.2.2, page 24).

**Table 6-1: Steps of creative process and activities of creative design**  
Source: Author-generated based on Zuo & Director (2000) model of conceptual design

| Phases of Creative Design | Activities involved  |
|---------------------------|--|
| <b>Analysis</b>           | 1. Analyse problem<br>2. Identify issues<br>3. Make decisions                              |
| <b>Synthesis</b>          | 4. Generate, update decision plans<br>5. Form Description                                  |
| <b>Evaluation</b>         | 6. Evaluate Description<br>7. Select the most appropriate solution and develop it further. |

The creative design phase, in general, is considered ideal for design trade-offs and managing complexities (discussed in Section 1.2.4 page 9). The multidimensional and multifaceted nature of sustainable design is expected to add to the complexity of design. This phase thus is expected to play a very significant role in incorporating sustainability consideration in the design. The following section attempts to develop morphology for sustainable design by integrating sustainability-related activities with the creative phase of traditional design morphology.

### 6.3. Proposing a Morphology for Sustainable Design

The activities involved in the creative phase of design across the stages of analysis, synthesis and evaluation under normal circumstances has already been enlisted in Table 6-1. This section at first draws corresponding activities for sustainable design, and then integrate them it with traditional design morphology.

#### 6.3.1. Activities for Sustainable Design

The first step of creative design is analysis. The corresponding step for sustainable design will be sustainability analysis. This step is concerned with exploring, identifying and prioritising the factors that are responsible for impacting products' sustainability. The comprehensive sustainability analysis should encompass the three broad dimensions of environment, society and economy (Sarkar, Rachuri, & Sriram, 2011). It should also be

carried out at three levels (product, lifecycle and system). The ten directions for sustainability derived in Chapter 4 acts as a framework for sustainability analysis.

The second step of creative design is synthesis that is generating solution concepts based on the analysis. The corresponding step for sustainable design includes making a decision on problem-solving strategy and generating alternative concepts (abstract solution) for increasing the sustainability of the product. At this stage, the proposed directions for sustainability guides the concept generation. The sustainability interaction matrix helps designers in understanding the implications of their decisions by identifying the conflicts between different directions.

The third step of creative design is an evaluation that is focussed on selecting the most appropriate concepts from alternative concepts. The corresponding step of sustainable design includes evaluating the sustainable design solution based on the ten directions for sustainability and selecting the most appropriate solution alternative. Table 6-2 summarises the recommended list of activities for creative sustainable design.

Table 6-2: Recommended list of activities for sustainable design

Source: Author-generated

| Stages of creative design | Recommended activities | Description  |
|---------------------------|------------------------|--|
| <b>Analysis</b>           | Explore                | Explore all the possible factors at product, lifecycle and system level that impacts the directions for sustainability |
|                           | Identify               | Identify the factors that have potential to effect (directly or indirectly) the given problem and context              |
|                           | Prioritise             | Prioritise the factors according to the extent of their impact   |
| <b>Synthesis</b>          | Strategy               | Make strategy of problem solving (orienting the direction of problem solving) based on directions for sustainability   |
|                           | Conceptualise          | Conceptualise alternatives of sustainable design based on the strategy   |
| <b>Evaluation</b>         | Evaluate               | Evaluate the alternatives based on the direction of sustainability   |
|                           | Select                 | Select the most appropriate concept and develop it further   |

### 6.3.2. Integrating the activities with Traditional Morphology

Sustainable design activities include sustainability analysis, synthesis for sustainability and sustainability evaluation for selection of the most sustainable solution. This thesis

proposes that these activities should be integrated with the traditional morphology of design, as demonstrated in Figure 6.2.

Sustainability analysis for the product to be designed (or redesigned) is recommended to be carried out along with the ‘analysis of task’ phase. The analysis includes three basic activities of exploration, identification and prioritisation (using the framework of sustainable design), elaborated in the following section.

Synthesis for sustainability is recommended to be carried out with the conceptual design phase. It consists of deciding on the strategy for conceptual design (based on the prioritisation in the previous step) and generation of alternative solutions. The interaction matrix of direction for sustainability (refer figure 4.6, page 78) can be used for strategy making and conceptualising.

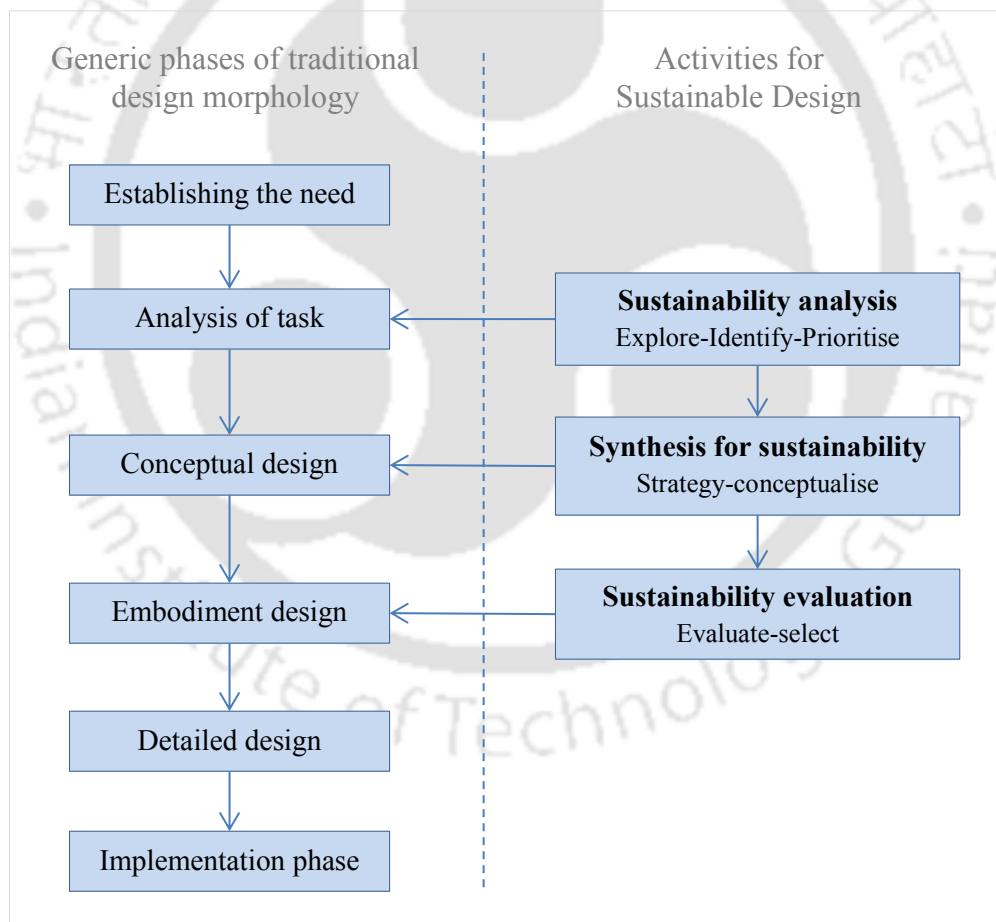


Figure 6-2: Proposed model of Morphology for Sustainable Design

Source: Author-generated

Evaluation of alternative solutions and selection of the most sustainable solution is recommended to be carried out during embodiment design phase. The proposed directions for sustainability can be used for evaluation as shown in figure 6.2.

The following sections elaborate on the activities of sustainable design. Section 6.3.3 discusses the sustainability analysis; Section 6.3.4 elaborates on synthesis for sustainability, and finally Section 6.3.5 discusses the sustainability evaluation part.

### 6.3.3. Sustainability Analysis

Sustainability analysis consists of exploring, identifying and prioritising the factors that affect the environmental, social and economic dimension of sustainability. It utilises the sustainable design framework derived in chapter 4, illustrated in Table 4-7 (page 80) for the analysis.

#### 6.3.3.1. Environmental Sustainability Analysis

Environmental sustainability analysis focuses on exploring, identifying and prioritising the issues that affect the environmental dimension of sustainability at product, lifecycle and system levels. Table 6-3 illustrates the four directions to be explored.

Table 6-3: Directions for environmental sustainability

Source: Author-generated

| Directions for environmental sustainability | Guidance for analysis   |   |  |
|---|---|---|--|
|   | Product-level   | Lifecycle level   | System level   |
| Sustaining Resources                        | Major resources that are being /will be consumed in manufacturing the modules/parts of product like energy and materials          | Major resources that are being /will be consumed at different stages of the lifecycle like land, water, energy, etc.  | Major resources that bring/will be consumed due to products effect on the system.                              |
| Maintaining ecological systems              | Factors within product or its parts/modules having potential of affecting the ecological systems and causing irreversible changes | Lifecycle stages that have a significant effect on ecological systems and can cause irreversible changes in biodiversity loss, ecological cycle's disturbance, etc. | Factors that affect the system impact on ecological systems  |
| Regulating environmental impact             | Product and its modules/parts that impact environment like toxic and hazardous substances, waste, generally irreversible.         | Lifecycle phases that impact environment like the production of toxic and hazardous substances waste.   | Factors that affect the system in production of environmental impact like toxicity production waste generation |
| Developing environmental awareness          | Product or its modules/parts where there is a lack of information that can be helpful for the decision makers                     | Lifecycle stages where information is most needed for environmental friendly decision-making  | Information availability that may lead to environmental friendly decision making within the system             |

### At product level

At this level, the effect of the product on the four directions of environmental sustainability is explored, identified and prioritised. One of the possible ways of doing is as follows:

*Step 1:* Break the product to be designed or re-designed into modules/parts and explore all factors that affect the four directions for environmental sustainability.

*Step2:* Identify the factors that are under the control (directly or indirectly) of the designer.

*Step 3:* Prioritise the factors based on the significance and extent of the impact on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high). Use the suitable method for consolidating the findings of the analysis. For example Table 6-4 can be used, where total score one will reflect which module/part is responsible for highest impact and total score two will reflect the dominant reason for the impact.

**Table 6-4: Prioritisation table for product-level environmental sustainability analysis**

Source: Author-generated

| Directions for environmental sustainability | Part 1 | Part 2 | ..... | Part n | Total score 2 |
|---|--------|--------|-------|--------|---------------|
| Resource consumption                        |        |        |       |        |               |
| Impact on ecological systems                |        |        |       |        |               |
| Environmental impact                        |        |        |       |        |               |
| Environmental awareness                     |        |        |       |        |               |
| Total score 1                               |        |        |       |        |               |

### At Lifecycle level

At this level, the effect of the products' lifecycle on the four directions of environmental sustainability is explored, identified and prioritised. One possible way of is as follows:

*Step 1:* Draw the different lifecycle stages of the product to be designed or re-designed and explore the lifecycle stages that affect the four directions of environmental sustainability.

*Step2:* Identify the factors that are under the control (directly or indirectly) of the designer.

*Step 3:* Prioritise the factors based on the significance and extent of the impact on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high). Table 6-5 can be used

for consolidating the findings of the analysis. Total score 1 will reflect which lifecycle stage handles the highest impact, and total score 2 will reflect the dominant reason for impact.

**Table 6-5: Prioritisation table for product-level environmental sustainability analysis**

Source: Author-generated

| Directions for environmental sustainability | Material extraction and processing | Product manufacturing | ..... | End of life stage | Total score 2 |
|---|------------------------------------|-----------------------|-------|-------------------|---------------|
| Resource consumption                        |                                    |                       |       |                   |               |
| Impact on ecological systems                |                                    |                       |       |                   |               |
| Environmental impact                        |                                    |                       |       |                   |               |
| Environmental awareness                     |                                    |                       |       |                   |               |
| Total score 1                               |                                    |                       |       |                   |               |

#### At System level

At this level the effect of products' system on the four directions of environmental sustainability is explored, identified and prioritised. One of the possible ways of doing is as follows:

*Step 1:* Draw a system level map where the product to be designed or re-designed is a part and explore how various system components affect the four directions of environmental sustainability.

*Step 2:* Identify the factors that are under the control (directly or indirectly) of the designer.

**Table 6-6: Prioritisation table for product-level environmental sustainability analysis**

Source: Author-generated

| Directions for environmental sustainability | System component 1 | System component 2 | ..... | System component n | Total score 2 |
|---|--------------------|--------------------|-------|--------------------|---------------|
| Resource consumption                        |                    |                    |       |                    |               |
| Impact on ecological systems                |                    |                    |       |                    |               |
| Environmental impact                        |                    |                    |       |                    |               |
| Environmental awareness                     |                    |                    |       |                    |               |
| Total score 1                               |                    |                    |       |                    |               |

*Step 3:* Prioritise the factors based on the significance and extent of the impact on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high). Table 6-6 can be used for consolidating the findings of the analysis. Total score 1 will reflect which system component is responsible for highest impact, and total score 2 will reflect the dominant reason for impact.

### 6.3.3.2. Social Sustainability Analysis

Social sustainability analysis attempts to explore, identify and prioritise all the factors that impact the three directions of social sustainability at product, lifecycle and system levels. Table 6-7 illustrates the directions to be explored.

Table 6-7: Social sustainability analysis framework

Source: Author-generated

| Directions for social sustainability | Guidance for analysis   |  |  |
|--------------------------------------|---|--|--|
|                                      | Product-level   | Lifecycle level  | System level   |
| Developmental social sustainability  | Product and its use that influences the fulfilment of basic and higher-order needs  | Factors that affects fulfilment of basic and higher order needs of stakeholders at different stages of the lifecycle   | System-level factors affecting fulfilment of basic needs and higher order needs of stakeholders                                |
| Bridge social sustainability         | User behaviour while using the product is leading to wastage of resources, disturbance in ecology, etc.   | Stakeholders' behaviour at different lifecycle stages of the product is leading to wastage of resources, disturbance in ecology and impacts the environment. | Stakeholders' behaviour is leading to wastage of resources, disturbance in ecology and impacts the environment at system level |
| Maintenance social sustainability    | Product use affecting the user preferences that they would like to be maintained like traditions, cultural preferences, religious practices, etc. | Stakeholders' preferences that they would like to be at different life cycle stages of product   | Stakeholders' preferences that they would like to be maintained are affected within the system                                 |

#### At product level

At product level the effect of the product on the three directions of social sustainability is explored, identified and prioritised. The focus is on the society (people) product interaction. One of the possible ways of doing is as follows.

*Step 1:* Identify the primary user of the product to be designed or re-designed.

*Step 2:* Explore in what way the use of the product is negatively affecting the fulfilment of basic needs (pure air, portable water, health, services etc.) and higher order needs (like building social cohesion, removing social exclusion etc.) of the user.

*Step 3:* Explore how the user behaviour while using the product is leading to wastage of resources, disturbance in ecology and impacts the environment. Identify how such behaviours can be changed into eco-friendly behaviour leading to environmental awareness.

*Step 4:* Explore how the product use is affecting the user preferences that they would like to be maintained like traditions, cultural preferences, religious practices, etc. Also explore the user behaviour related to the use of a product which they prefer and would like to be maintained.

*Step 5:* Based on the significance and extent of impact explored and identified in step 2 to step 4, prioritise on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high) the three directions of social sustainability. Table 6-8 can be used to consolidate the findings where score 1 will reflect the most environmental impacting behaviour/use and score 2 will reflect the dominant nature of the impact.

**Table 6-8: Prioritisation table for product level social sustainability analysis**  
Source: Author-generated

| Directions for social sustainability | User 1 | User behaviour 1 | User behaviour 2 | ----- | User behaviour n | Score 2 |
|--------------------------------------|--------|------------------|------------------|-------|------------------|---------|
| Developmental social sustainability  |        |                  |                  |       |                  |         |
| Bridge social sustainability         |        |                  |                  |       |                  |         |
| Maintenance social sustainability    |        |                  |                  |       |                  |         |
| Score 1                              |        |                  |                  |       |                  |         |

### **At lifecycle level**

At this level, the impact of products' lifecycle stages on the society is explored in the three directions of social sustainability. It involved all the stakeholders living in the society.

*Step 1:* Identify all the stakeholders involved with different stages of the product's lifecycle.

*Step 2:* Explore how the fulfilment of basic needs (pure air, portable water, health, services etc.) and higher order needs (like building social cohesion, removing social exclusion etc.) of stakeholders are affected at different stages of the lifecycle.

*Step 3:* Explore how the stakeholders' behaviour at different lifecycle stages of the product is leading to wastage of resources, disturbance in ecology and impacts the environment. Identify how the design of the product can influence such behaviours into eco-friendly behaviour leading to environmental awareness.

*Step 4:* Explore how the different lifecycle stages of the product are affecting the stakeholders preferences that they would like to be maintained like traditions, cultural preferences, religious practices, etc. Also explore the user behaviour related to the use of a product which they prefer and would like to be maintained.

*Step 5:* Based on the significance and extent of impact explored and identified in step 2 to step 4, prioritise on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high) the three directions of social sustainability. Table 6-9 can be used to consolidate the findings where score 1 will reflect the most environmental impacting behaviour/use and score 2 will reflect the dominant nature of the impact.

**Table 6-9: Prioritisation table for lifecycle level social sustainability analysis**  
Source: Author-generated

| Directions for social sustainability | Stakeholder behaviour stage 1 | Stakeholder behaviour stage 2 | ---- | Stakeholder behaviour stage n | Score 2 |
|--------------------------------------|-------------------------------|-------------------------------|------|-------------------------------|---------|
| Developmental social sustainability  |                               |                               |      |                               |         |
| Bridge social sustainability         |                               |                               |      |                               |         |
| Maintenance social sustainability    |                               |                               |      |                               |         |
| Score 1                              |                               |                               |      |                               |         |

#### **At system level**

The impact of the system on society in the three directions of social sustainability is explored, identified and prioritised.

*Step 1:* Draw system levels map where the product to be designed or re-design is a part, and identify all the stakeholders involved.

*Step 2:* Explore how the fulfilment of basic needs (pure air, portable water, health, services, etc.) and higher order needs (like building social cohesion, removing social exclusion, etc.) of stakeholders are affected by the product.

*Step 3:* Explore how the stakeholders' behaviour is leading to wastage of resources, disturbance in ecology and impacts the environment. Identify how the design of the product can influence such behaviours into eco-friendly behaviour leading to environmental awareness.

*Step 4:* Explore how the product is affecting the stakeholders' preferences that they would like to be maintained like traditions, cultural preferences, religious practices, etc. Also explore the user behaviour related to the use of a product which they prefer and would like to be maintained.

*Step 5:* Based on the significance and extent of impact explored and identified in step 2 to step 4, prioritise on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high) the three directions of social sustainability. Table 6-10 can be used to consolidate the findings where score 1 will reflect which stakeholder is causing maximum impact and score 2 will reflect the dominant nature of the impact.

**Table 6-10: Prioritisation table for lifecycle level social sustainability analysis**  
Source: Author-generated

| Directions for social sustainability | Stakeholder 1 | Stakeholder 2 | ---- | Stakeholder n | Score 2 |
|--------------------------------------|---------------|---------------|------|---------------|---------|
| Developmental social sustainability  |               |               |      |               |         |
| Bridge social sustainability         |               |               |      |               |         |
| Maintenance social sustainability    |               |               |      |               |         |
| Score 1                              |               |               |      |               |         |

### 6.3.3.3. *Economic Sustainability Analysis*

Economic sustainability analysis attempts to explore, identify and prioritise all the factors that impact the three directions of economic sustainability at product, lifecycle and system level. Table 6-11 illustrates the three directions for economic sustainability.

Table 6-11: Economic sustainability analysis framework

Source: Author-generated

| Directions for economic sustainability | Guidance for analysis  |  |  |
|--|--|--|--|
|  | Product-level  | Lifecycle level  | System level   |
| Sustenance of economic growth          | Products' features that do not add value to the producer and consumer - identify features that add value   | Factors that has potential of increasing the products value for the customer as well as producer across the lifecycle stages (like introduction, growth maturity and decline) of the product   | Factors that can strengthen the product's market position and competition. Also, look for future long-term business opportunities. |
| Building natural capital               | Product features that the not efficient and has a potential of improvement contributing to resource efficiency   | The factors that are not efficient across the lifecycle stages and leads to wastage of resources harms environment and ecology   | Factors that are not efficient and leads to wastage of resources, - opportunity for efficient technologies                         |
| Building social and human capital      | Product features that have potential of building competencies among user by providing information, knowledge - identify features that will increase social cohesion and social interaction | Factors across product's lifecycle (introduction, growth, maturity and decline) that have potential of building competencies among user by providing information, knowledge - features that will increase social cohesion and social interaction | System that are affected by the product building social and human capital  |

### At product level

At product level the effect of the product on the three directions of economic sustainability is explored, identified and prioritised. One of the possible approaches to doing is as follows.

*Step 1:* Explore and identify the products' features that do not add value to the producer and consumer.

*Step 2:* Explore and identify the products' features that is not efficient and has a potential of increase in efficiency.

*Step 3:* Explore and identify products' features and functions that have a potential of social and human capital building. Identify where there is a lack of information which when provided to users will lead to competency building.

*Step 5:* Based on the significance and extent of impact explored and identified in step 2 to step 3, prioritise on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high) the three directions of economic sustainability. Table 6-12 can be used to

consolidate the findings where score 1 will reflect the most economic impacting factors and score 2 will reflect the most dominant impact.

**Table 6-12: Prioritisation table for product level economic sustainability analysis**

Source: Author-generated

| Directions for economic sustainability | Product feature/function 1 | Product feature/function 2 | ----- | Product feature/function n | Score 2 |
|--|----------------------------|----------------------------|-------|----------------------------|---------|
| Sustenance of economic growth          |                            |                            |       |                            |         |
| Building natural capital               |                            |                            |       |                            |         |
| Building social and human capital      |                            |                            |       |                            |         |
| Score 1                                |                            |                            |       |                            |         |

#### **At lifecycle level**

At lifecycle level, the effect of product's lifecycle on the three directions of economic sustainability is explored, identified and prioritised. One of the possible approaches of doing is as follows.

*Step 1:* Explore and identify all the factors that have the potential of increasing the products' values at different stages of the lifecycle (like introduction, growth, maturity and decline).

*Step 2:* Explore and identify the factors that are not efficient across the lifecycle stages (introduction, growth, maturity and decline) leading to wastage of resources and harms environment and ecology.

*Step 3:* Explore and identify how social and human capital can be built at different stages of the products' lifecycle.

*Step 5:* Based on the significance and extent of impact explored and identified in step 2 to step 3, prioritise on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high) the three directions of economic sustainability. Table 6-13 can be used to consolidate the findings where score 1 will reflect the most economic impacting factors and score 2 will reflect the dominant nature of the impact.

Table 6-13: Prioritisation table for lifecycle level economic sustainability analysis

Source: Author-generated

| Directions for economic sustainability | Factor 1 | Factor 2 | ---- | Factor n | Score 2 |
|--|----------|----------|------|----------|---------|
| Sustenance of economic growth          |          |          |      |          |         |
| Building natural capital               |          |          |      |          |         |
| Building social and human capital      |          |          |      |          |         |
| Score 1                                |          |          |      |          |         |

**At system level**

At the system level, the effect of the product-service system on the three directions of economic sustainability is explored, identified and prioritised. One of the possible approaches of doing is as follows.

*Step 1:* Explore and identify all the factors that have the potential of strengthen the product's market position against competition.

*Step 2:* Explore and identify the factors that are not efficient and leads to wastage of resources, seek opportunities for efficient technologies and business models.

*Step 3:* Explore and identify the factors that have the potential for building social and human capital within the product service system.

Table 6-14: Prioritisation table for product-service level economic sustainability analysis

Source: Author-generated

| Directions for social sustainability | Factor1 | Factor 2 | ---- | Factor n | Score 2 |
|--------------------------------------|---------|----------|------|----------|---------|
| Developmental social sustainability  |         |          |      |          |         |
| Bridge social sustainability         |         |          |      |          |         |
| Maintenance social sustainability    |         |          |      |          |         |
| Score 1                              |         |          |      |          |         |

*Step 4:* Based on the significance and extent of impacting factors explored and identified in step 1 to step 3, prioritise on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high) the three directions of economic sustainability. Table 6-14 can be used to consolidate the findings where score 1 will reflect the most economic impacting factors and score 2 will reflect the dominant nature of the impact.

#### 6.3.3.4. Consolidating the Finding of Sustainability Analysis

The exploration, identification and prioritisation of 10 directions for sustainability (environment, society and economy) carried above can be consolidated in a radar diagram. Radar diagrams are efficient tools for visualisation of consolidated finding. This is expected to present the overall picture of the directions that need to be improved. Consolidate the rating carried out for environment, social and economic dimensions on a scale of 1 to 5 (1=very low, 2=low, 3=medium, 4=high, 5=very high) and illustrate in the radar diagram, as shown in Figure 6-3.

This radar diagram acts as a visualisation tool for understating the direction of sustainability impact and deciding on the strategy for synthesis phase. At synthesis phase, mitigating steps should be taken to improve the situation by reducing those impacts.



Figure 6-3: Radar to consolidate the findings of sustainability analysis

Source: Author-generated

### 6.3.4. Synthesis for Sustainability

Synthesis for sustainability consists of 2 activities - strategy formation and alternative solution creation (conceptualisation). The consolidated radar diagram for sustainability analysis created in the previous section is used as a basis for strategy formation. The strategy should be in the direction of sustainability direction that has high priorities.

For example: let us consider that the direction of ‘developing environmental awareness’ have been rated high priority during analysis, the strategy should be development of environmental awareness by providing features and information at product, lifecycle and system levels that improves environmental awareness.

| ↑ - complementary<br>↓ - conflicting<br>↔ - mutually complementary<br>↕ - contextual | Sustaining Resources | Maintaining ecological systems | Regulating environmental impact | Developing environmental awareness | Developmental social sustainability | Bridge social sustainability | Maintenance social sustainability | Sustaining economic growth | Building natural capital | Building social and human capital |
|--|----------------------|--------------------------------|---------------------------------|------------------------------------|-------------------------------------|------------------------------|-----------------------------------|----------------------------|--------------------------|-----------------------------------|
| Sustaining Resources   |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Maintaining ecological systems   |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Regulating environmental impact  | ↑                    | ↕                              |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Developing environmental awareness   | ↑                    | ↑                              | ↑                               |                                    |                                     |                              |                                   |                            |                          |                                   |
| Developmental social sustainability  |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Bridge social sustainability   | ↑                    | ↑                              | ↑                               | ↕                                  | ↕                                   |                              |                                   |                            |                          |                                   |
| Maintenance social sustainability  | ↓                    | ↓                              | ↓                               | ↕                                  | ↓                                   | ↕                            |                                   |                            |                          |                                   |
| Sustaining economic growth   | ↓                    | ↓                              | ↓                               |                                    | ↑                                   |                              | ↓                                 |                            |                          |                                   |
| Building natural capital   | ↑                    |                                | ↑                               | ↕                                  |                                     |                              |                                   | ↓                          |                          |                                   |
| Building social and human capital  | ↑                    | ↑                              | ↑                               | ↕                                  |                                     | ↑                            | ↑                                 | ↕                          | ↑                        |                                   |

Figure 6-4: Interaction matrix of sustainability directions

Source: Author-generated

At this point, the sustainability interaction matrix proposed in Section 4.3.4 (see Figure 6-4) will help in understating what other directions could be affected by the decisions made. If the relationship is complementary, then it will have a positive impact on sustainability, but if the relationship is conflicting then, the designer have to a trade-off between the two directions.

Such conflicting situation on one hand present challenges for the designer, while on the other hand provides him/her an opportunity for breakthrough innovation through conflict resolution (Domb & Dettmer, 1999). Such conflicting situations in the sustainability interaction matrix have similarity with the TRIZ conflict resolution matrix. Resolution of conflicts will lead to a “win-win” solution.

### 6.3.5. Evaluation of Design Alternatives

The evaluation of design alternatives consists of finding the most sustainable solution. Evaluation radar diagram shown in Figure 6.5 is used for the evaluation of design alternatives. The proposed solution should be rated on a scale of -1 to 3 based on their performance in ten directions for sustainability.



Figure 6-5: Radar for sustainability evaluation of design alternatives

Source: Author-generated

If a design solution is given '0' in a certain direction, then it means that there is no improvement in that direction. If a solution is given '1' it represents incremental improvement; similarly '2' represents significant improvement; '3' represent breakthrough innovation; '-1' represents a deterioration in performance. Rating all the design solution alternatives will visually show the most sustainable solution and which direction has been improved for sustainability.

#### 6.4. Conclusion

This chapter catered to the third research gap identified in section 2.6.3 (page 49) and was concerned with answering RQ4 (and achieving OB4, page 16). This research gap identified the need for a morphological approach for sustainable designing. Chapter 4 of the thesis revealed that the understanding of sustainable design in literature is varied and derived a comprehensive framework. The empirical study reported in Chapter 5 revealed that the traditional morphology of design has limited scope in sustainable designing, and there is a need of improved design morphology. This chapter proposed morphology of sustainable design based on the findings of chapter 1 and chapter 2.

This morphology proposes the activities of sustainable design (sustainability analysis, synthesis for sustainability and sustainability evaluation) to be integrated with the traditional morphology of design. The proposed morphology uses the ten directions for sustainability as a basis for analysis, synthesis and evaluation. The sustainability direction interaction matrix was used for taking a conscious decision on conflicting directions. This morphology is an improvement over the traditional design morphology in the context of sustainable design and is expected to be useful for novice creative designers in incorporating sustainability into their design. The following chapter tests this morphology through dry run using a mobile phone as a sample product.



## Chapter 7

(Phase 3)

# Validating the Proposed Morphology of Sustainable Design

This chapter is focused on validating the morphology of sustainable design, which was proposed in Chapter 6. Validation was done through the dry run (practice testing) using mobile phone as a sample product. The chapter is concerned with research question RQ5 (OB5) and attempts to demonstrate how a morphological approach for sustainable designing is likely to affect the creative design phase and its output. It was expected that such an approach towards sustainable design will lead to new directions for increasing the sustainability of any product.

## 7.1. Introduction

This chapter attempts to validate the sustainable design morphology proposed in the previous chapter (chapter 6) and is concerned with RQ5 (illustrated in Section 1.4, page 16). The proposed morphology integrates the activities of sustainable design (Table 6-2, page 122) with the traditional design morphology, and uses the sustainable design framework (refer Section 4.4, page 80) with interaction matrix for sustainability directions (refer Section 4.3.4, page 78). This implies that if we test the usefulness of the sustainable design framework (and interaction matrix) in carrying out the activities of sustainable design, it will validate the morphology as well (as marked in Figure 7.1).

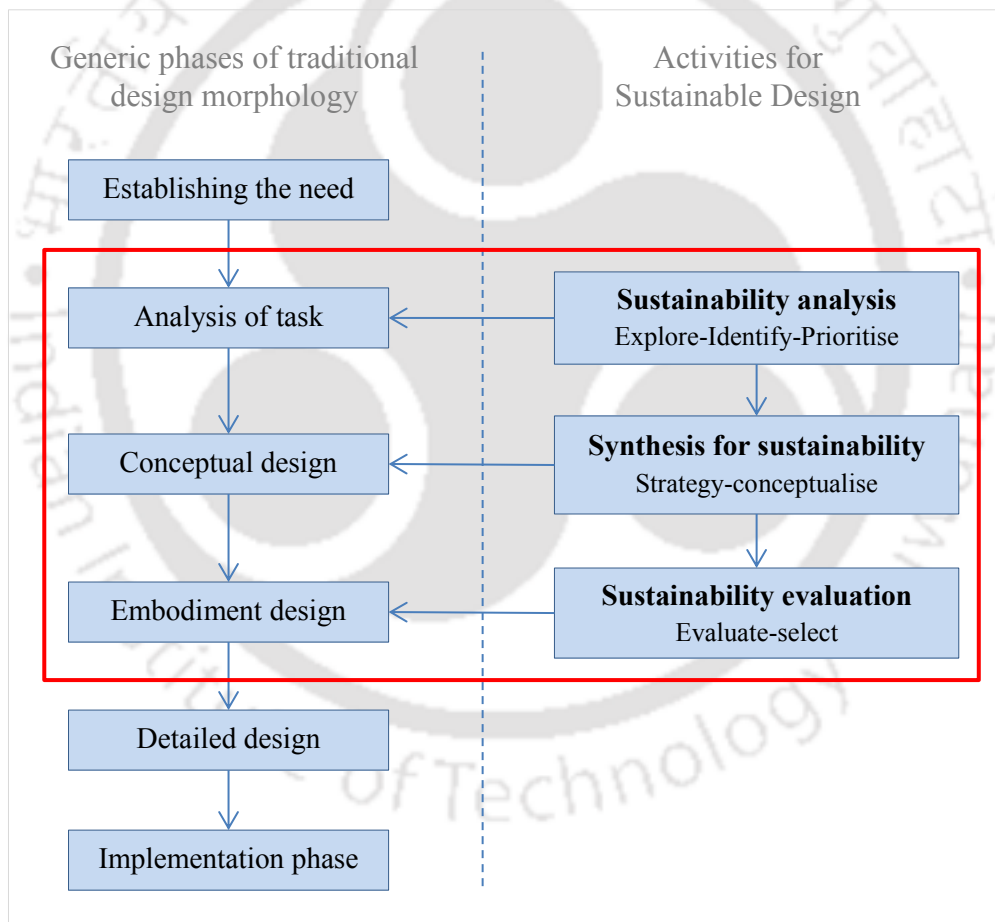


Figure 7-1: Part of proposed model of Morphology for validation

Source: Author-generated

This chapter employs the following two methods for validating the proposed morphology.

1. Dry Run Testing (also known as practice testing) and
2. An Empirical Study

A dry run (or a practice run) is a validation process usually employed for software program where the programmer examines the algorithm's procedures one step at a time. The test was conducted with the aim of demonstrating how the proposed morphological approach for sustainable product designing is likely to affect the creative design phase and its output. A mobile phone was used as a sample product for a dry run.

For empirical validation the sustainable design framework (along with interaction matrix) was introduced as a part of sustainable design course and a set of 2 similar task was given, one before the introduction of framework and one after to study its effect (elaborated in Section 7.5).

This chapter also tests the posit P3 as restated below.

**P3:** A morphological approach for sustainable product designing reveal new directions for incorporating sustainability in design.

The chapter at first reports the dry run and then the empirical study. It starts with an introduction to the mobile phone as an e-waste, and why it was chosen as a sample product for testing. It then elaborates on the procedure for testing. The sustainability analysis of mobile phone is presented in section 7.3 using the proposed sustainable design framework (discussed in section 4.4, page 75). Sustainability issues associated with a mobile phone at product, lifecycle and system level is explored from environmental, social and economic dimensions. Section 7.4 presents the synthesis, which elaborates on the various ways in which sustainability of mobile phones can be improved based on the findings of sustainability analysis. This section also points out inter and intra dimensional conflicts. Section 7.5 reports the empirical study conducted, and Section 7.6 verifies the working posit P3. The chapter concludes with the consolidated findings of the dry run and empirical study.

## 7.2. Dry Run Testing Using Mobile Phone as a Sample Product

A mobile phone (sometimes also called cellular phone, cell phone or hand phone) is a two-way radio, which sends and receives radio signals, carrying voice and data in personal communication with other mobile phones, and telephones (Singhal, 2005). Structurally they very complex devices with a high number of components, most of which are made up of a large variety of material composition (Singhal, 2005).

Discarded mobile phones fall under the category of ‘e-waste’ or ‘electronic waste’ that itself is a subset of Waste Electrical and Electronic Equipment (WEEE) (EU WEE Directives, 2002). E-waste is referred to old, end-of-life electronic appliances such as computers, laptops, TVs, DVD players, mp3 players, etc., disposed of by their original users (Yammiyavar & Kumar, 2011). Table 7-1 shows a common list e-waste (Robinson, 2009).

**Table 7-1: List of common e-waste (under WEEE)**

Source: (Robinson, 2009)

| Items                       | Weight (in kg) | Typical Life (in yrs.) |
|-----------------------------|----------------|------------------------|
| Computer                    | 25             | 3                      |
| Facsimile Machines          | 3              | 5                      |
| High-Fidelity Systems       | 10             | 10                     |
| <b>Mobile Phones</b>        | <b>0.1</b>     | <b>2</b>               |
| Electronic Games            | 3              | 5                      |
| Photocopier                 | 60             | 8                      |
| Radio                       | 2              | 10                     |
| Television                  | 30             | 5                      |
| Video Recorder & DVD Player | 5              | 5                      |

### 7.2.1. Why Mobile Phones

From Table 7-1, it can be observed that mobile phones by weight shares only a small portion of total e-waste (Robinson, 2009). However, the literature reflects concerns about its sustainability owing to following reasons (Cobbing, 2008).

1. **Versatile devices:** Within a period of times it evolved from a voice transmitting device to a device which supports a variety of services like text messaging, MMS, email, Internet, short-range wireless communications (infrared, Bluetooth), business applications, gaming and photography. Shortly with the maturity of technologies like cloud computing, mobile phones are expected to support more general computing and thus could be a replacement for many more computing devices. The device is also expected to support many new business and services, making it a very versatile device. M-commerce, M-healthcare, M-banking, etc. are few such examples. These predictions make this device very important from a sustainability perspective.

2. **Exponential growth rate:** The global subscription of mobile phones has grown from 12.4 million in the year 1990 to over 6.9 billion in 2014 which is 95.5% of the total world population (ITU, 2014). It is expected to overshoot the 100% in coming few years.
3. **High obsolescence rate:** The typical life of a mobile phone is considered from 7 to 10 years, but most of the devices are disposed by their first user in 12-24 months only (Huang, Yatani, Truong, Kientz, & Patel, 2008). This user behaviour is mainly due to technological obsolescence, and fashion trends that are often pushed by manufacturers through advertisements, and other such methods (Paiano, Lagioia, & Cataldo, 2013). High obsolescence rate of mobile phones leads to high discard rate. These discarded mobile phones contained very rare and precious metals, few of them are very toxic and harmful, if not disposed of properly. According to one of the estimates, the global e-waste contribution in the year 2008-2009 was about 200,000 tons (Yammiyavar & Kumar, 2011).
4. **Potential social impact:** The device being versatile with very high penetration rate and is expected to have huge social impacts starting from health, support for community service, social cohesion, social exclusion to being a medium for many other societal impacts.

Apart from these factors, the toxic nature of material used, high energy requirements during production & use, presence of rare and precious materials in construction etc. (Yammiyavar & Kumar, 2011) were the motivating factors behind taking it as a product for dry run.

### 7.2.2. Procedure for Dry Run Testing

The proposed morphology for sustainable design recommends the integration of three activities of sustainability analysis, synthesis for sustainability and sustainability evaluation with the traditional morphology of design morphology as shown in figure 6-2 (page 119)

At first the sustainability analysis of mobile phone is conducted, covered in Section 7.3. Based on the analysis, synthesis for sustainability is presented in Section 7.4. This section instead of conceptualising mobile phone limits itself in suggesting ways in which sustainability of a mobile phone can be improved. It also highlights on inter and intra dimensional conflicts and elaborates on one of the conflicts. Section 7.5 discusses

the method of sustainability evaluation. Finally, the chapter concludes with a discussion on posit testing, and major inferences from the test.

### 7.3. Sustainability Analysis of Mobile Phones

This phase of the proposed morphology attempts to explore, identify and prioritise the impacts on the ten directions for sustainability at product, lifecycle and system levels. At first environmental sustainability analysis is presented in Section 7.3.1 followed by the social and economic analysis presented in Section 7.3.2 and 7.3.3. Section 7.3.4 consolidates the findings of the analysis.

#### 7.3.1. Environmental Sustainability Analysis

Environmental sustainability analysis of mobile phone attempts to explore, identify and prioritise all the aspects and factors of the device that are responsible for negative impact on the directions for environmental sustainability discussed in Section 6.3.3.1 (see Table 6-3, page 124). The analysis is presented at the product level, lifecycle level and system levels.

##### 7.3.1.1. *Product Level Analysis for Environmental Sustainability*

At this level, the attempt was to understand how mobile phone as a product affects the four directions for environmental sustainability. It explored the construction, modules, parts and components of a mobile phone and their possible impact on environmental sustainability. In general product-level environmental sustainability analysis corresponds with the concept of green design (see Section 4.3, Figure 4.1, page 63). It is mainly concerned with factors like material reduction, toxicity potential, and energy consumption, etc. as an important parameter of environmental impact. Literature presents several product level analysis of mobile phones (Nnorom & Osibanjo, 2009) (B. Y. Y. Wu, Chan, Middendorf, Gu, & Zhong, 2008) (Yammiyavar & Kumar, 2011) (Yamane & Moraes, 2011), and this study uses the data generated by them.

For the study purpose three mobile phones of different price ranges were collected, all from the same manufacturer who has the largest market share in India (Cobbing, 2008). The mobile phones were voluntarily donated for study purpose by their owners. The devices were marked as sample A, B and C. Sample A was the costliest (INR 10,000) bought in December 2007; still in working condition. Sample B costs around INR 5,500 and bought in July 2008; not in working condition and the owner kept

it in case it can be repaired. Sample C was a basic handset costing about INR 2,200 and was in working condition bought in November 2007.



Figure 7-2: Product sample study of a mobile phone (Major modules of sample A, B and C)

Source: Author-generated

At first, the material composition was estimated for the sample mobile phones. For this, the sample phones (Sample A, Sample B, Sample C) were weighted and then disassembled. Figure 7.1 illustrates the disassembled hardware of the three sample phones. All the sub-assembly were physically measured. The material composition in the subassembly was then estimated using the specific gravity of the material. This estimate was cross-checked with published similar attempts for other phones (B. Y. Wu, Chan, Middendorf, Gu, & Zhong, 2008). Table 7-2 shows the result of the composition of materials.

Table 7-2: Material composition of the sample mobile phones A, B and C as estimated

Source: Author-generated

| Sample   | Total Weight (g) | Plastic (g) | Metal (g) | Ceramic (g) | Others (g) |
|----------|------------------|-------------|-----------|-------------|------------|
| Sample A | 110              | 47          | 38        | 13          | 12         |
| Sample B | 104              | 46          | 36        | 12          | 10         |
| Sample C | 91               | 40          | 32        | 11          | 8          |

It can be observed from Table 7-2 that ratio wise there is not much difference of material composition across the three models analysed. Table 7-3 illustrates the metal contents as generally found in mobile phones, and its value ratio. It can be observed that the value ratio of metals like Gold (Au), Palladium (Pd), Silver (Ag), and Copper (Cu) have the highest value (Yu, Williams, & Ju, 2010). According to an estimate if all the waste mobile phones generated in 2008 were formally recycled, more than 1250 tons Cu, 480 tons Fe, 13 tons Ag, 3 tons Au, and 2 tons of Pd would be recovered (Yu et al., 2010).

Table 7-3: Average metal content and value ratio of typical mobile phones

Source: (Yu et al., 2010)

| Elements        | Cu  | Al  | Fe  | Ni  | Pb   | Sn  | Ag   | Au    | Pd   |
|-----------------|-----|-----|-----|-----|------|-----|------|-------|------|
| Content (%)     | 13  | 2   | 5   | 0.1 | 0.3  | 0.5 | 0.14 | 0.035 | 0.02 |
| Value ratio (%) | 4.3 | 0.3 | 0.2 | 0.1 | 0.03 | 0.6 | 3.9  | 78.8  | 11.8 |

Literature reports that there are many materials in a mobile phone that have high toxicity potential. Figure 7.2 shows the approximate toxicity potential (in percentage) of different materials found in a typical mobile phone. Although there may be a slight variation in the composition of materials depending on the manufacturer and the cost of the mobile phone, but Cobalt (Co), Nickel (Ni), Copper (Cu), Chromium (Cr), Lead (Pb) accounts for the highest toxicity potential.

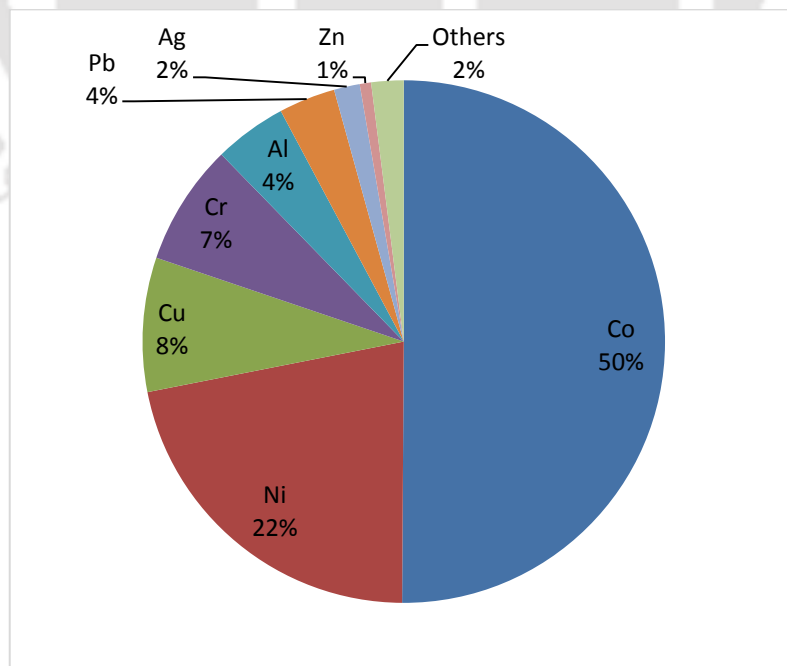


Figure 7-3: Material wise toxicity potential

Source: (B. Y. Y. Wu et al., 2008)

From the above discussion, it can be observed that a mobile phone consumers some of the most precious metals and materials with high toxicity potential. Apart from these two factors, the mobile phones construction, their module/part was also explored. Figure 7.3 shows the classification of major modules/parts of the mobile phone (including hardware and software). The software consists of the operating system and the various application programs. Hardware consisted of modules/parts like the outer casing, printed circuit board/ printed wiring board (PCB/PWB), a display unit (TFT/LCD), battery, etc.

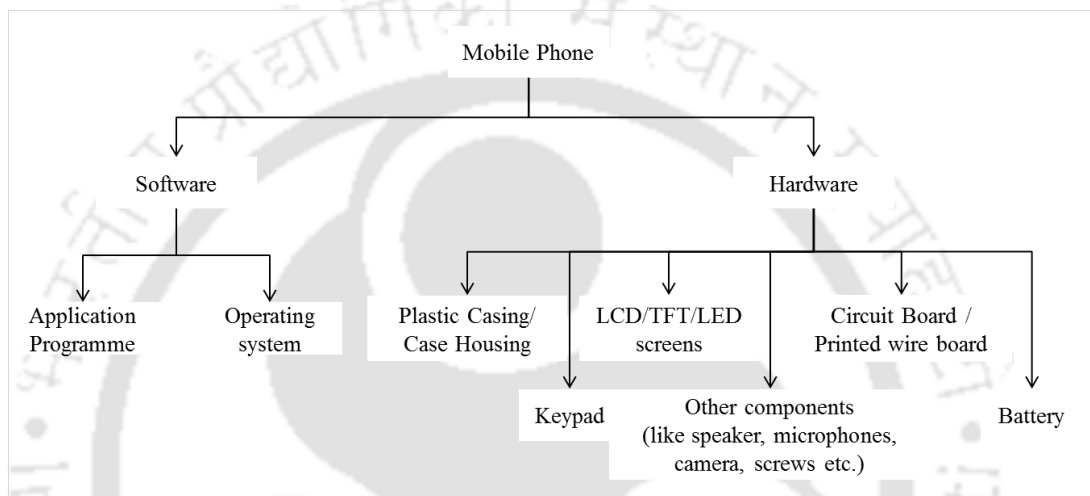


Figure 7-4: Major constituents of a mobile phone

Source: Author-generated

These modules studied and available literature was referred in order to understand their impact on four directions for environmental sustainability. The main reason for choosing module level exploration is the fact that creative designers work at module/part level and are not fascinated in knowing the intricate technical details. Their approach starts at whole then to parts and then to details.

### Plastic casing/plastic housing

Plastic casing/housing forms the outer shell of a mobile phone. It protects the inner components and gives an attractive visual quality to the device.

*Sustaining Resources:* Materials and energy were identified as major resources consumed. Materials consists of plastics like polycarbonate, ABS-PC etc. with plastic stabilizers and colour pigments like cadmium (Cd) (Singhal, 2005)(Five Winds (2001) as cited in (Osibanjo & Nnorom, 2008)). Exact data on energy consumed in manufacturing was not found, but it was expected to be very low (less than 1%) (Osibanjo & Nnorom, 2008).

*Maintaining Ecological Systems:* Literature does not report any significant impact on the ecological system.

*Regulating Environmental Impact:* The plastic casing contains traces of heavy metals like Lead (Pb), Nickel (Ni) and Silver (Ag), but it does not pose any significant danger to the environment (Nnorom & Osibanjo, 2009). The open burning of the casing/housing has the potential of forming toxic by-products if treated at low or moderate temperature but not very significant (Nnorom & Osibanjo, 2009).

*Developing Environmental Awareness:* No information for the user was found on the casing/housing for developing environmental awareness. Providing information may have some potential.

### **Frame/plate**

Metal plates and plastic frame houses the LCD screen buttons and PCB along with other components like the speaker, camera, etc. It was difficult to remove the frame as all other components have to be removed.

*Sustaining Resources:* Material and energy were recognised as the major resources consumed. Materials included plastic, iron (Fe), Nickel (Ni) and contains heavy metals like including Cadmium (Cd) (Osibanjo & Nnorom, 2008) (Nnorom & Osibanjo, 2009). The energy consumed in manufacturing is comparatively very low.

*Maintaining Ecological Systems:* Literature does not report any significant potential danger for ecological systems.

*Regulating Environmental Impact:* Although, it contains heavy metals like Cadmium (Cd) but does not pose a significant threat to the environment.

*Developing Environmental Awareness:* The frame/plate does not contain any information that can be used for development of environmental awareness.

### **Printed circuit board (PCB)/printed wired Board (PWB)**

After removing the screws from the frame, PCB/PWB is exposed, holding other modules like speakers, microphone, camera, processor ICs, SIM card slot, and memory slots.

*Sustaining Resources:* It is the most resource intensive parts with a major contribution from materials and energy used (Singhal, 2005). Printed circuit boards of the mobile phone are the FR-4 type and composed of multi-layers of epoxy resin, fiberglass coated with a copper layer (Yamane & Moraes, 2011). The typical composition of such a

PCB/PWB is 63% metals, 24% ceramics and 13% polymers by weight. They are categorised under the high-grade PCB/PWB as the concentration of gold is more than 100 ppm. Apart from gold it also contains other precious metals like silver, palladium, platinum, and copper (Rochat, 2008). The concentration of copper has been found to be as high as 33-35% by weight and is increasing in newer mobile phones (Yamane & Moraes, 2011). These metals can act as an incentive for recycling, but at the same time have high toxicity potential and are a serious health and environmental threat if not handled appropriately (T. Wu & Y.J, 2008)(Lim & Schoenung, 2010).

PCB/PWB is the most energy intensive component of the mobile phone. It uses the most energy intensive materials. PCB/PWB along with ICs accounts for about 59% of total handsets' environmental impact in production and recycling (Fishbein, 2002).

*Maintaining ecological systems:* PCB/PWB of a mobile phone has been recommended to be classified as hazardous waste by US EPA (Fishbein, 2002). If it is dumped with normal waste, these poisonous substances may leach from decomposing waste in landfills, seep into groundwater and contaminate the soil. The metals in the soil can enter the food chain and in sufficient concentrations may cause health problems. Lead is among the most common hazardous material that is used as tin-lead solder in PCB and PWBs (Singhal, 2005) (Fishbein, 2002). A typical mobile phone contains about one gram of lead. However, recent mobiles have phased out the use lead-containing solders in PCB/PWB. These factors make PCB/PWB significant from ecological system's perspective.

*Regulating Environmental Impact:* PCB/PWB contains the most toxic substances and has the very high potential for environmental impact. It contains toxic substances like copper, arsenic, lead, antimony, mercury and zinc.

1. Brominated and chlorinated flame retardants that are used in the epoxy resins of PCB/PWB. Antimony in the form of antimony trioxide is also used as a flame retardant in PCB/PWB and could cause toxicity if not properly recycled (Osibanjo & Nnorom, 2008).
2. Beryllium in copper-beryllium alloy that is used at connecting points of PCB/PWB with external wires and devices. Its amount can vary from 3 mg to 0.1 g per mobile phone depending upon manufacturer and model (Singhal, 2005).
3. Arsenic that is used in the manufacture of gallium arsenide semiconductor, as a dopant in silicon wafers, and to manufacture arsine gas used to make integrated

circuits. A typical mobile phone may contain less than 1 mg of gallium arsenide (Singhal, 2005) (Fishbein, 2002).

These factors make PCB/PWB very significant part in regulating environmental impact.

*Developing Environmental Awareness:* General awareness about the environmental impact, material intensity and energy intensity of the PCB/PWB is very low. According to one of the study only 49% of mobile users know about recycling services and only .001-.003% of electronic equipment are recycled each year (Dailytekk.com, 2014). Studies have found out that in Indian context there is a general unwillingness to hand over their old mobile sets for recycling and formal disposal. Probable reasons can be - perceived value of users in broken handsets, emotional attachment, lack of awareness, lack of collectors and recyclers (Yammiyavar & Kumar, 2011). Developing environmental awareness about this module/par can play a very significant role.

### **Mobile Display**

A connector connects the TFT-LCD screen with the PCB/PWB and can be removed very easily. Thin film transistor-liquid crystal display (TFT-LCD) is a variant of liquid crystal display (LCD) which uses thin film transistor (TFT) technology to improve image quality.

*Sustaining Resources:* Its main content is glass along with traces of arsenic, antimony, barium, chromium and nickel. According to an environmental assessment conducted by Nokia, mobile phones LCDs account for 39 % of the total environmental impact caused by production and recycling (Singhal, 2005). In recent years due to the advent of touch screen technology, there is a trend towards larger displays that can further increase the environmental impact caused due to displays.

*Maintaining Ecological Systems:* Literature does not report any significant impact of TFT-LCD impact on ecological systems.

*Environmental Impacts:* Toxicity potential wise TFT-LCD is not considered hazardous but following elements can cause serious threat if not managed properly at the end of life (AEAT, 2006).

1. Mercury is used as vapours in light to illuminate LCD screens and in fluorescent tubes that illuminate the display of mobile phones (Singhal, 2005). Typically 5 mg is used per screen but as the screen size increases the quantity will also increase.

2. The solid form of polycyclic aromatic hydrocarbon (PAHs) is used as liquid crystals in mobile phone displays. It poses a threat when released during an uncontrolled incineration of LCDs (Singhal, 2005).

*Developing Environmental Awareness:* No information was available on the TFT-LCD screens that could tell the user about its toxicity potential. Its recycling is comparatively energy intensive and promoting reuse can be a better strategy.

### **Battery**

Battery can be removed and replaced after removing the back cover of the outer casing.

*Sustaining Resources:* Depending upon the type of battery the materials used changes. A mobile phone may contain manganese dioxide and nickel if it has a NiCd or NiMH battery (Osibanjo & Nnorom, 2008). The energy used in manufacturing battery is comparatively very low.

*Maintaining ecological systems:* No significant ecological impact of the battery was reported in the literature.

*Regulating environmental impact:* Battery contains chemicals like lithium, cadmium, manganese dioxide. It is a potential threat for environmental as it exceeds the hazardous waste threshold limit (AEAT, 2006).

*Developing Environmental Awareness:* A typical battery depending upon use lasts from 1.5 years to 3 years. It can be very easily removed and replaced with a new battery. The graphics on the battery mentions that it should not be discarded as normal waste. However, it has been found that in Indian context most of the old batteries (nearly 95%) do not reach the formal recycling plants. It is either kept in user's home or dumped along with normal garbage. This behaviour can be very damaging. Developing awareness among users about its toxic nature can have significant improvement.

### **Keypad**

*Sustaining Resources:* Keypad is made of a combination of plastic and rubber. The energy used in manufacturing keypad is comparatively very low.

*Ecological and environmental impacts:* Its toxicity depends on the materials used for colour coating or treatment. In general, no significant threat to the environment was reported in the literature. However, the evolution of touchscreen technology (resistive and capacitive) is slowly replacing the keypad, and it becomes obsolete.

## Software

Software in a mobile phone consists of the operating system and the application program installed on the device.

*Sustaining Resources:* Limited research is available which discusses the environmental impact of operating systems and application programs in the context of a mobile phone. It is certain that certain amount of energy goes into developing the software.

*Ecological and environmental impact:* There is no significant ecological and environmental impact of software.

*Developing Environmental awareness:* Operating system and application programs have a tremendous potential towards developing environmental awareness, however; the sample phones lack such information.

Table 7-4 consolidates the environmental sustainability analysis at the product level. All the major modules/parts which have been discussed are rated on a 5 point scale based on the discussion (1= very low, 2 = low, 3 = medium, 4 = high, 5 = very high).

Table 7-4: Consolidated product level environmental sustainability analysis

Source: Author-generated

| Directions for environmental sustainability | Casing/housing | Frame/plate | PCB/PWB | TFT/LCD | Battery | Keypad | S/W | Score 2 |
|---|----------------|-------------|---------|---------|---------|--------|-----|---------|
| Sustaining resources                        | 2              | 2           | 5       | 4       | 2       | 1      | 2   | 18      |
| Maintaining ecological systems              | 1              | 1           | 4       | 2       | 1       | 1      | 1   | 11      |
| Regulating environmental impact             | 2              | 1           | 5       | 4       | 4       | 1      | 1   | 18      |
| Developing environmental awareness          | 2              | 1           | 4       | 4       | 3       | 1      | 5   | 20      |
| Score 1                                     | 7              | 5           | 18      | 14      | 10      | 4      | 9   |         |

From the table 7-4 it can be observed at product level, developing environmental awareness should be given 'high' priority whereas sustaining resources and regulating environmental impact are equally important direction for environmental sustainability and is of 'medium' priority. Maintaining ecological system has 'low' priority. Moreover, within a mobile phone PCB/PWB and TFT/LCD accounts for the highest environmental

impact. Battery and software should also be given importance. Software has a huge potential and can play a very significant role in establishing environmental sustainability.

### 7.3.1.2. Lifecycle Level Analysis for Environmental Sustainability

This analysis attempted to explore, identify and prioritise the factors that affect the 4 directions of environmental sustainability at various stages of mobile phone's lifecycle. It provided a holistic lens from material extraction stage to disposal stage and helped in identifying the opportunities for improving environmental sustainability. Figure 7.4 illustrates the typical stages of the mobile lifecycle that start on drawing board where designers and engineers conceptualize it depending upon the user's need and market requirement. This is the stage where most of the decisions about the sustainability of any product are taken (Design Council, 2002). Thus, designers have the tremendous opportunity of controlling and avoiding the negative impact of any product on environment, society and economy. A thorough understanding of the whole life cycle of the product is thus needed. It will empower creative designers with the knowledge where their interventions could make the product more sustainable.

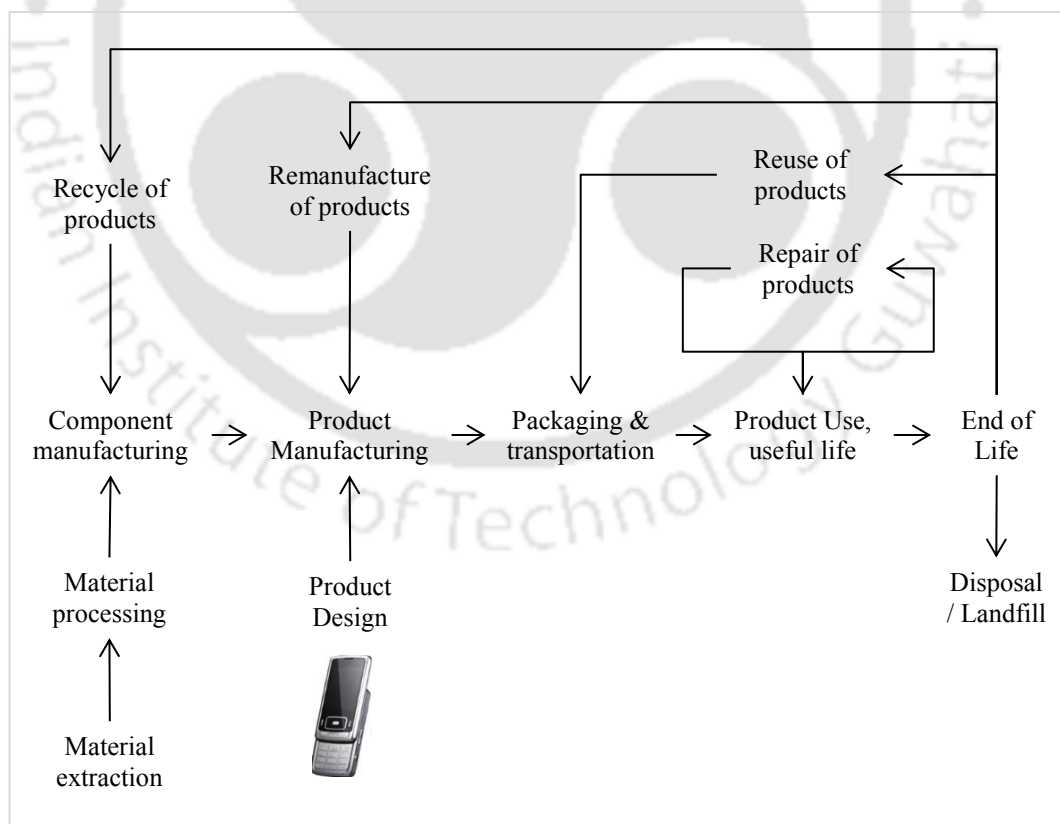


Figure 7-5: Typical life cycle stages of a mobile phone and general end of life treatment

Source: Adapted from (Jofre & Morioka, 2005)

The following paragraphs explored the possibility of designer's intervention step by step throughout the life cycle of a mobile phone.

### Material Extraction and Processing

Mobile phones need a host of materials like copper, gold, silver, palladium, aluminium, petroleum, etc. in various amounts for manufacture. Section 7.3.3.1 has already discussed these materials, and Table 7-3 shows the prominent materials that are found in mobile phones.

*Sustaining Resources:* The material extraction and processing require many resources out of which the most important are energy, water, land and chemicals. The process of material extraction predominantly uses land (from which the raw material is extracted), water (for various mining activities) and energy (for mining activities). After extraction material is processed, this involves a series of operations that transforms raw material into industrial materials. The processing requires resources like energy, water, various types of chemicals. The amount of resources consumed per unit extraction and processing of materials used in mobile phones need to be accounted. However, there is a lack of readily available data on water consumption, land uses, chemicals used, etc. So for simplicity only energy consumption has been taken as a parameter of resource consumption.

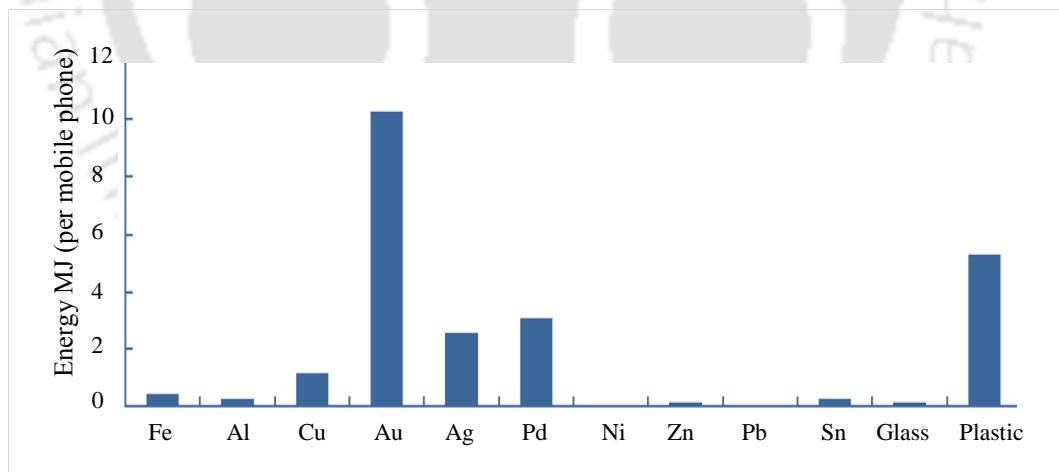


Figure 7-6: Energy consumed in the extraction of raw materials needed for mobile phone components

Source: (Yu et al., 2010)

One of the estimates reflects that about 23 MJ of energy is consumed in material extraction and processing stage for a single a mobile phone (Yu et al., 2010). Out of which Gold (Au), Plastic, Silver (Ag) and Palladium (Pd) accounts for about 90% of the total energy consumed (see Figure 7.5). Weight wise materials like gold, silver, palladium

share only a very small percentage in a mobile phone but in terms of energy required in extraction and processing, they are the highest energy intensive materials.

*Maintaining ecological systems:* The material extraction processes significantly affects the maintenance of ecological systems. Most of the metals in their ore form have to be dug out of the ground affecting the land use, loss of biodiversity, deforestation, contamination of soil, contamination of ground and surface water, air pollution, etc. (Larmer, 2009). According to estimates, 691,000 litres of water is being consumed in producing 1 kg of gold containing cyanide and other contaminants. When released in the river streams it poses a significant danger to aquatic systems.

*Regulating Environmental Impact:* The major environmental impact of material extraction and processing phase are caused by the waste produced which sometimes can be toxic, toxic chemicals used in the processing of materials, water consumed, air pollution, water pollution etc. Contamination of soil, contamination of ground and surface water, air pollution, etc. are other environmental impacts (Larmer, 2009).

*Developing environmental awareness:* Environmental awareness among the stakeholders at this stage can be very helpful in decision making. For example the information regarding materials' impact on the environment and ecological system, its energy intensity, etc. can be very useful for designers in devising the appropriate strategy for making more sustainable products.

### **Product Manufacturing**

The product manufacturing stage consists of component manufacturing and then assembly. The stage may happen at one location or many locations. The parts are manufactured at many places and assembled at one place.

*Sustaining Resources:* The most prominent resources that are consumed during component manufacturing are materials and energy. Assembly process is more energy and labour intensive. PCB/PWB (with all the active components like ICs and passive components like capacitors and resistors) and LCD/TFT screens are the most energy intensive component in a mobile phone. It has been estimated that about 120 MJ of energy is consumed in manufacturing the components for a single mobile phone and nearly 2 MJ in assembly (Yamaguchi et al., 2003; Singhal, 2005; Hoffman, 2003 as cited in (Yu et al., 2010)). The PCB/PWB alone accounts for about 40% of the total energy whereas nearly 50% to Integrated circuits (ICs) (Aryana & Boks, 2010)(Rathore, Kota, &

Chakrabarti, 2011). Figure 7.6 illustrates the percentage share of energy spent on manufacturing the components of mobile phones.

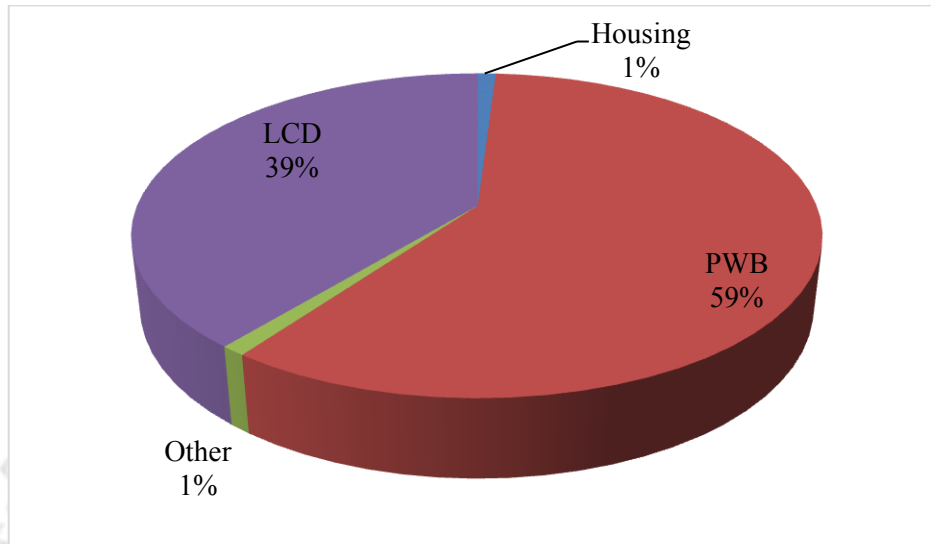


Figure 7-7: Share of energy spent in manufacturing mobile phone components (in %)

Source: Fishbein, 2002 as cited in (Osibanjo & Nnorom, 2008)

*Maintaining ecological systems:* The component manufacturing produces a lot of toxic substances that may be a threat to the ecological systems.

*Regulating environmental impact:* The manufacturing process releases a host of greenhouse gases into the atmosphere and toxic substances.

*Developing environmental awareness:* Developing awareness among the component manufacturers about handling the toxic substances during production and treatment of water before releasing it into the river stream holds a significant potential.

### **Packaging and transportation**

Once the mobile phone is assembled, it is packed and transported to the retailers. Depending upon the place of manufacture, they are shipped through various modes of transportation.

*Resource consumption:* The resources used for packaging are cardboard boxes and plastic. Transportation consumes energy in the form of petroleum and electricity. The energy required for packaging and transportation depends on the manufacturer and make & model of the mobile phones. Packaging weight and distance of transportation decides on the resource and energy consumption. According to an estimate, the energy consumption can be in the range of 10 MJ to 60 MJ (Singhal, 2005 as cited in (Yu et al., 2010)).

*Maintaining ecological systems:* In general the packaging does not pose any significant threat to the ecological systems.

*Regulating environmental impacts:* Literature does not report any major environmental impact from packaging as mostly biodegradable materials are used. However, transportation has the potential of air pollution.

*Environmental awareness:* A lot of information and graphic is displayed on the packaging, but there is a lack of information regarding environmental awareness.

### **Product Use Phase**

This is a phase when the product is purchased and used by its first user.

*Sustaining Resources:* The main resource that is consumed during use phase is energy. Energy is consumed during charging and standby discharging. According to an estimate it can vary from 32 MJ per year to 65 MJ per year (Rosen and Meier, 2000) (Schaefer et al., 2003; Lawrence Berkeley National Laboratory, 2010) depending upon the mobile phone manufacturer and usage behaviour.

*Maintaining ecological systems:* No significant ecological impact during the use phase of a mobile phone has been reported.

*Regulating environmental impact:* Literature does not report any significant environmental impact during the use phase of a mobile phone apart from inappropriate disposal of used battery.

*Environmental awareness:* Use phase of mobile phone have significant opportunities in spreading environmental awareness through application programs. This phase can also help in encouraging environmental-friendly behaviour.

### **End of Life (EoL) Phase**

Once the mobile phone is discarded by the first user, the mobile phone comes to the end of life phase. Sustainability aspect depends on how it is treated. Few of the possible alternatives, depending upon the mobile phone are as follows.

1. The phone lays idle with the first user for a long time and finally end up being disposed of with the normal waste. In such cases, a mobile phone may be a threat to ecology and environment as various toxic substances may leach into soil and groundwater.

2. The mobile phone is given to a second user either without any repair or with the repair. In this case, there is no ecological or environmental threat and the only resource that will be consumed is energy.
3. The mobile phone is discarded by original user and is sent for refurbishing or remanufacturing. In this case, there is no significant resource consumption or impact on ecological and environmental impact.
4. The device is given to a formal recycler. In this case, the resource consumed is energy and chemicals for recycling.
5. The device reaches a non-formal recycler. In this case, there can be significant environmental and ecological impact and the resource consumed will be energy. A designer has great potential in designing for these several paths in the end of life.
6. The precious and high energy intensive materials like gold, silver, copper, etc. can act as the incentive for recycling. However, according to estimates, in India only 5% of the total e-waste reaches the formal recycling plants (Yammiyavar & Kumar, 2011).

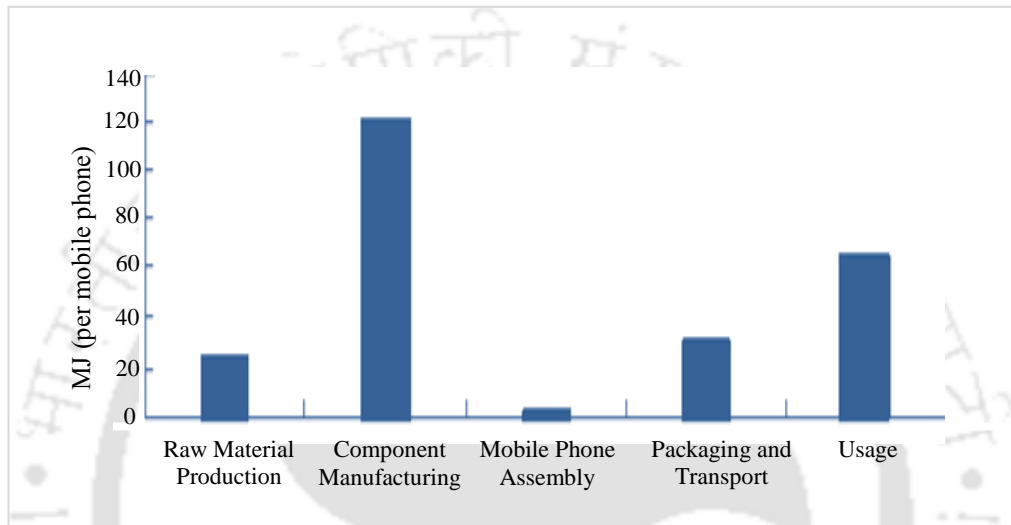
In all the cases mentioned above, environmental awareness has the potential of playing a significant role. Table 7-5 consolidates the environmental sustainability analysis at lifecycle level. All the major lifecycle stages which have been discussed are rated on a 5 point scale based on the discussion (1= very low, 2 = low, 3 = medium, 4 = high, 5 = very high).

**Table 7-5: Consolidated environmental sustainability findings**

Source: Author-generated

| Directions for environmental sustainability | Material extraction & processing | Product manufacturing | Packaging & Transportation | Product use | End of life (EoL) | Score 2 |
|---|----------------------------------|-----------------------|----------------------------|-------------|-------------------|---------|
| Sustaining resources                        | 5                                | 5                     | 3                          | 4           | 4                 | 21      |
| Maintaining ecological systems              | 5                                | 3                     | 1                          | 1           | 4                 | 14      |
| Regulating environmental impact             | 4                                | 4                     | 1                          | 1           | 4                 | 14      |
| Developing environmental awareness          | 3                                | 4                     | 3                          | 5           | 5                 | 20      |
| Score 1                                     | 17                               | 16                    | 8                          | 11          | 17                |         |

From the table 7-5, it can be observed that at lifecycle level, sustaining resources and developing environmental awareness comes out to the 'high' priority for environmental sustainability. Maintaining ecological systems and regulating environmental impact is rated 'medium' in priority. Moreover, the stages of material extraction manufacturing and end of life account for the highest impacts on environmental sustainability.



**Figure 7-8: Energy consumed during the lifecycle of a mobile phone**  
Source: Adopted from (Yu et al., 2010)

Figure 7.7 shows the amount of energy consumed during the various stages of a mobile phone. It can be observed that component manufacturing stage has the highest impact followed by usage stage. However, the only parameter of measurement was energy consumed and may not provide a comprehensive view. In comparison, Table 7-5 provides a more comprehensive view that suggests that material extraction and processing, and end of life stages should be given more priority compared to the manufacturing stage.

### 7.3.1.3. System Level Analysis for Environmental Sustainability

This section explores the factors that affect the environmental sustainability at a system level. Owing to the versatility of the mobile phone, the device has become an important part of many systems like mobile banking, e-commerce, etc. However, here only mobile phone network system is considered for analysis. Figure 7.8 illustrates the major components of a mobile phone network system. It consists of mobile phone unit, base transceiver station (BTS), base station controller (BSC), mobile switching centre and

PSTN (Public Switched Telephone Network). The following paragraphs elaborate on the impact of this system on four directions of sustainability.

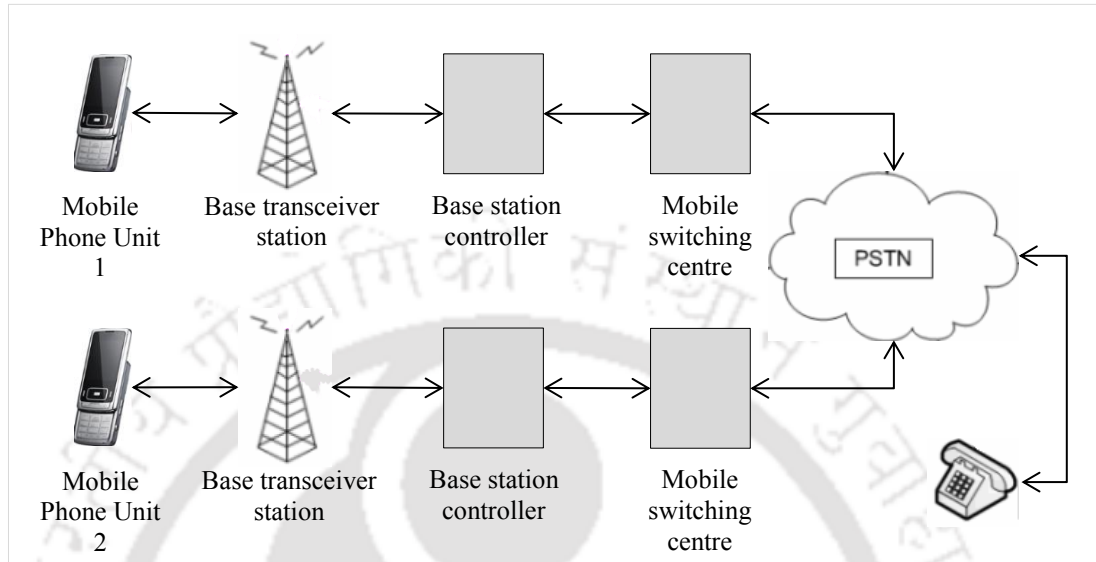


Figure 7.9: Mobile phone network system (simplified)

Source: Author-generated

*Sustaining Resources:* The resources that are consumed by the mobile phone systems are material, energy, and land. A huge amount of material is needed for the construction of BTS, BSC, mobile switching centre and PSTN. Literature does not report any study for materials consumed in the construction of the system. These systems also use the land for construction and operation.

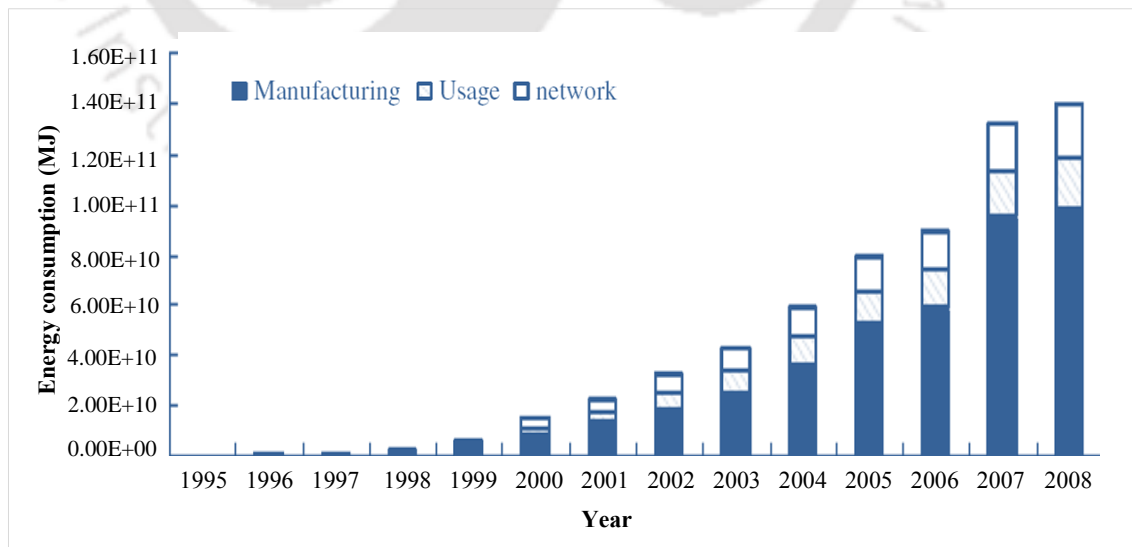


Figure 7.10: Comparative trend of energy usage by mobile phones during manufacturing, usage and network

Source: (Osibanjo & Nnorom, 2008)

According to one of the studies conducted in China in 2008, it was estimated that 5763 GWh per year is consumed by the network (Osibanjo & Nnorom, 2008). Out of which switching equipment consumes most of the energy followed by BTSs and BSCs. The estimates reflect that network infrastructure consumes about 33 MJ per year per subscriber in China (Osibanjo & Nnorom, 2008). Figure 7.9 shows the comparative energy consumption during manufacturing, usage and network consumption. That's why it is rated 'medium' on priority.

*Maintaining ecological systems:* The base transceiver station's radiation is known to have some effect on certain species of birds. Apart from this the system is not known to have any significant effect on ecological systems and is thus rated 'very low' on priority.

*Regulating Environmental Impact:* The improper disposal of e-waste generated from base station controller and mobile switching centre may have an environmental impact. A change in technology leads to a change in equipment. However, their impact has not been reported in the literature and is thus rated 'low' in priority.

*Developing Environmental Awareness:* The system provides a limited scope for environmental awareness and is rated 'very low' on priority.

### 7.3.2. Social Sustainability Analysis

The social sustainability analysis is concerned with exploring and identifying the factors that are responsible for negative impact on the three directions of social sustainability, as discussed in section 4.3.2 (page 70). It also attempts to identify the opportunities through which the three directions of social sustainability can be improved. Following sections presents this analysis at product, lifecycle and system levels.

#### 7.3.2.1. Product Level Analysis for Social Sustainability

At the product level, the analysis attempts to explore how a product (here a mobile phone) negatively impact the developmental, bridge, and maintenance aspect of society (people). It also attempts to identify opportunities in which the product can be improved for creating a positive impact on the society. The factors/variable are then prioritised on a scale of 1 to 5 indicating the level of concern (1-very low; 2 -low; 3-medium; 4-high; 5-very high). The following paragraphs present the analysis.

### **A. Developmental Social Sustainability**

As stated in section 4.3.2.1 (page 72), this direction of social sustainability concerns the fulfilment of basic needs (like pure air, portable water, health services, healthy food, health and medication, energy, power, freedom, education, employment, justice, access to decision making etc.), and higher order needs (like building social capital, social cohesion, removing social exclusion, conserving and enhancing resource base etc.) of society. Limited literature was found that discussed how mobile phone as a device influences the developmental aspect of society.

The mobile phone as a product, in general, is not known to pose any significant threat in fulfilling the basic needs of the society. In many cases, it was found to be supportive in achieving these needs, like mobile-based health services, access to education, access to employment, capacity for decision making, etc. However, there are concerns regarding user behaviour that has the potential of affecting water quality and health. Improper disposal of mobile phone battery (and the phone as a whole) may lead to water contamination. The Literature reported few health concerns of using mobile phones (especially in children) out of which the most prominent is mobile phone radiation.

The contradicting view is seen in terms of achieving the higher order needs of people like building social capital, social cohesion, and removing social exclusion, etc. On one hand mobile phone as a device is connecting people from all over the world, bringing communities together, and building social cohesion. While on the other hand there is concern about the virtual nature of cohesion. It is observed that a lot of time is spent on the phone in the virtual world, rather than interacting in real time. Mobile phone addiction is one of the factors that may have a significant effect on developmental social sustainability. Apart from these factors, the device was found to have a positive effect on developmental social sustainability and was thus rated 'low' on priority.

### **B. Bridge Social Sustainability**

As stated in section 4.3.2.2 (page 72), this direction of social sustainability is focussed on promoting eco-friendly behaviour, environmental ethics and bridging the gap between people and the bio-physical environment. With the current usage pattern, mobile phone as a product has great potential in this direction.

In the current context, a mobile phone is more than just a device for communication. It has multiple uses, starting from acting as a platform for shopping to a device for suggesting health tips. Therefore, it has a tremendous potential towards

promoting environmental friendly behaviour. One of the methods of doing so is by providing the user with appropriate information that will sensitise them towards changing their behaviour in a positive direction.

For example, literature points out that in the Indian context, a mobile phone after its useful life is not given for formal recycling. According to an estimate, only 3% mobile phones in India reaches formal recycling facility (Yammiyavar & Kumar, 2011). Lack of information about the environmental impact of disposing of a mobile phone (or its battery) is the prominent reasons for this behaviour. According to another estimate 32 MJ per year to 65 MJ per year (Rosen and Meier, 2000) (Schaefer et al., 2003; Lawrence Berkeley National Laboratory, 2010) energy is spent on charging a mobile phone, depending upon the mobile phone manufacturer and the usages behaviour of user. One of the user behaviour that can reduce the energy consumption is by unplugging the charger as soon as the mobile is charged. The existing mobile phones (product samples) were found to provide very limited support for transforming such behaviours of people towards environmental friendliness. Moreover, it does not provide any information regarding the toxic nature of its components and its impact on the environment. Necessary information and applications can be built within the product for users for mitigating environmental damaging user behaviour.

Considering the devices' potential in contributing towards bridge social sustainability, this direction was given 'very high' priority.

### **C. Maintenance Social Sustainability**

As stated in section 4.3.2.2 (page 68), this direction of sustainability focuses on maintaining the user preferences like their traditions, culture preferences, religious practices, etc.

Literature does not report any issue related to the impact of the mobile phone on traditional, cultural, or religious practices of users. The elaborate study is required in understanding the effect that is beyond the scope of this thesis. However, as far as maintaining user preferences are concerned, following two preferences were observed.

It was observed that user prefer to change their mobile phones with changing fashion and technological up gradation. It has been noted that in general, the life of a mobile phone is about seven years, however; it is discarded by its first user within 1.5 -2 years (Yammiyavar & Kumar, 2011). It should be noted here that this preference is in contrast with the environmental sustainability.

The other observation made was the reluctance of users towards donating their old broken phones for recycling. Factors like perceived value of broken phones, emotional attachment, lack of awareness, etc. may be responsible for this preference of users. This trend is more prevalent in underdeveloped or developing nations (Yammiyavar & Kumar, 2011). It can be noted that this preference also goes against environmental sustainability.

These user preferences although contributes to maintenance social sustainability, is in contrast with environmental sustainability. That's why 'medium priority is given to this direction of sustainability. Table 7-6 consolidates the findings of social sustainability analysis at the product level.

Table 7-6: Consolidate view on social sustainability at product level  
Source: Author-generated

| Social Sustainability Directions    | Priority at product level |
|-------------------------------------|---------------------------|
| Developmental social sustainability | 2 (low)                   |
| Bridge social sustainability        | 5 (very high)             |
| Maintain social sustainability      | 3 (medium)                |

### 7.3.2.2. *Lifecycle Level Analysis for Social Sustainability*

At lifecycle level, the analysis attempts to explore how product's lifecycle (here a mobile phone) negatively impacts the developmental, bridge and maintenance aspect of social sustainability. It also attempts to identify opportunities, in which the product can be improved for creating a positive impact on society. Figure 7.4 (page 152) illustrates the various lifecycle stages of a mobile phone, and its general end of life treatment. The following paragraphs present the analysis.

#### **A. Developmental social sustainability**

As discussed in section 7.3.1.2 (page 12), the material extraction and processing stage is responsible for a lot of air pollution, water and land contamination. However, the social impact of this stage has not been extensively studied and reported in the literature. For example gold extraction and processing is known to cause a huge impact on local environment. This is likely to affect the local communities in accessing basic needs like pure air, pure water, etc. This stage thus has a huge potential of causing a negative impact on developmental social sustainability.

The component manufacturing phase produces a lot of chemicals, which when not managed properly will affect the quality of air and water affecting local communities in accessing pure air and water. Another likely social impact of this stage is health risk of people involved in manufacturing. Efficient ways of material processing with low energy and water demand are continuously sought, but these are not directly under the direct control of creative designers involved in designing.

The assembly, packaging, and transportation phase do not produce a significant impact on air and water quality and has less impact on developmental social sustainability. However, the end of life phase if not managed properly can have a significant effect on groundwater, soil and air (already discussed in section 7.3.1.2, page 147) which can significantly affect local communities. In this context, literature presents cases where a developed nation dumps their used mobile phones to underdeveloped nations that have a lack of technological know-how in dealing with it. The low-end waste handling practices of these nations are a potential threat to the local population in meeting their basic needs. Shifting of manufacturing facilities to developing and under-developed nations is yet another factor that impacts developmental social sustainability.

Although, mobile phones lifecycle have high impact on air, water and land, likely to affect the basic needs of people, it is not under direct control of designer, and thus it is rated 'low' in priority.

#### **B. Bridge social sustainability**

At the material extraction and processing phase, it is important to make industries aware of the impact of their activities on local communities. Mitigating steps should be taken by them in this direction. Workers involved in material extraction and processing industries; local communities; other stakeholders should be involved and sensitised towards environmental protection through appropriate methods like seminars, awareness campaigns, etc. Governments can play a very important in this direction by introducing appropriate regulations.

People involved in component manufacturing, packaging and transportation should be made aware of the implications of their activity on society. They should be sensitised towards building a better system that reduces the social impact. In the use phase, the mobile phone as a device can be used for educating and sensitising people towards environmental protection. The device has potential of being used as a medium for changing their environmental impacting behaviours as discussed previously.

There is a huge scope towards building environmental friendly behaviours in stakeholders involved at the end of life stage of mobile phones. Users and informal recyclers should be made aware of the environmental impacting potential of mobile phones. In the Indian context, informal recycling is prevalent, involving activities like open burning that pose significant dangers to the people involved as well as air and water. Providing appropriate information with the device and its parts may be a possible mitigating step in this direction.

There is a huge scope of contributing towards bridge social sustainability at lifecycle stages, but most of it is outside the direct control of a designer. Owing to this reason 'low' priority is given to this direction of sustainability.

### **C. Maintain social sustainability**

The material extraction and processing phase has potential of affecting the preferred way of living. It has been observed that a change in land use pattern for mining purposes leads to the destruction of the forest, and significantly affect the tribal and local communities.

The manufacturing and transportation phase does not pose much significance in maintaining social sustainability. The product use phase has already been discussed in the previous section that elaborated on maintain social sustainability at the product level.

The end of life phase of the mobile phone does not pose any significant threat to traditional, cultural, religious practices of people.

It can be observed that the factors discussed above are not directly under the control of the designer. Thus low priority is given to this direction of social sustainability at lifecycle level. Table 7-7 consolidates the findings of social sustainability analysis at lifecycle level.

Table 7-7: Consolidate view on social sustainability analysis at lifecycle level

Source: Author-generated

| <b>Social Sustainability Directions</b> | <b>Priority at lifecycle level</b> |
|---|------------------------------------|
| Developmental social sustainability     | 2 (low)                            |
| Bridge social sustainability            | 2 (low)                            |
| Maintain social sustainability          | 3 (medium)                         |

### 7.3.2.3. *System Level Analysis for Social Sustainability*

At the system level, the analysis attempts to explore mobile phone system's influence on developmental, bridge and maintenance aspect of social sustainability. It also attempts to identify opportunities, in which the product can be improved such that the system creates a positive effect on the three directions of social sustainability. The mobile phone as a device in recent times is an important component of many systems like mobile banking, m-health, and m-commerce. For example recent fingerprint-based authentication feature of the mobile phone is an important aspect of mobile banking systems. However, here mobile phone network as a system has been considered for simplicity. Figure 7.8 (page 159) illustrates the various components of a mobile phone network system. The following section presents the analysis.

#### **A. Developmental Social Sustainability**

The components of a mobile phone system as illustrated in Figure 7.8 (page 159) is not known to cause any negative impact on meeting the basic or higher order needs of the society. That's why at the system level, the developmental social sustainability is rated 'very low' priority.

#### **B. Bridge Social Sustainability**

The components of the mobile phone system like base station transceiver, base station controller, mobile switching centre and PSTN network consumes a lot of energy in operation. This energy consumption can be reduced through sensitisation of people involved in ways of reducing the energy consumption. The various stakeholders like the network user; people involved in managing and operating the network can contribute towards energy efficiency by following energy saving practices. For example – if the user of the network talks less, it can reduce the energy consumption. Information regarding the potential use of renewable sources of energy for operating and managing networks can also lead to energy efficiency.

These approaches need to be applied at the system level, and a creative designer has limited scope towards contributing to bridge social sustainability at a system level. That's why this direction of sustainability at the system level is rated 'very low' on priority.

#### **C. Maintenance Social Sustainability**

The mobile phone system and its component, in general, do not pose any significant effect on the maintenance of social, traditional, cultural, and religious or any other

preferences of stakeholders involved. Moreover, a creative designer of products has a limited scope for controlling the maintenance aspect of social sustainability. That's why it is rated 'very low' on priority. Table 7-8 presents the consolidated priority rating at the system level for social sustainability directions.

Table 7-8: Consolidate view on social sustainability analysis at system level

Source: Author-generated

| Social Sustainability Directions    | Priority at system level |
|-------------------------------------|--------------------------|
| Developmental social sustainability | 1 (very low)             |
| Bridge social sustainability        | 1 (very low)             |
| Maintain social sustainability      | 1 (very low)             |

### 7.3.3. Economic Sustainability Analysis

The economic sustainability analysis is concerned with exploring and identifying the factors that are responsible for negative impact on the three directions of economic sustainability, as discussed in section 4.3.3 (page 73). It also attempts to identify the opportunities through which the three directions of economic sustainability can be improved. Following sections presents this analysis at product, lifecycle and system levels.

#### 7.3.3.1. *Product Level Analysis for Economic Sustainability*

At the product level, the analysis attempts to explore how a product (here a mobile phone) can improve in maintaining economic growth, build natural capital and contribute to social and human capital building. It attempts to identify the opportunities in which a product can contribute to economic sustainability and rate it on a scale of 1 to 5, indicating the level of concern (1-very low; 2 -low; 3-medium; 4-high; 5-very high). The following paragraphs present the analysis.

#### **A. Sustaining Economic Growth**

Mobile phone as a device has contributed significantly in many ways towards sustaining economic growth, especially of developing and under-developed nations. For example – usage of the mobile phone in Malaysia is playing a pivotal role in enhancing farmers' business through access and understanding of the market situation (Razaque, 2013). Similar kind of thing is observed in India also, where farmers are getting fast and easy access to information regarding their agriculture related problems. According to one of

the UN report (Lynn, 2010), as published by Reuters, the mobile phone has a tremendous potential towards improving the livelihoods of the poorest people in developing countries.

Owing to these positive effects on sustaining economic growth, it has been given ‘very low’ priority of concern.

### **B. Natural Capital Building**

As far as natural capital building is concerned mobile phone manufacturers yet need to take effective steps in this direction. Selection and use of renewable materials, efficient use of water resources, closing the material cycle through reuse, refurbishing, recycling etc. are among the few steps that can be taken by the manufacturers for building natural capital.

Owing to huge opportunities in this direction, it has been rated ‘high’ on priority.

### **C. Social and Human Capital Building**

The mobile phone as a device is known to contribute towards social and human capital building. Providing easy access to knowledge, education and competency building through mobile phone has been well reported in the literature (Valk, Rashid, & Elder, 2010). Moreover, it has been known to produce quality and quantity in social interaction, bringing people together for information sharing. It was rated ‘low’ on priority because of its contribution towards social and human capital building.

Table 7-9 presents the consolidated priority rating at the product level for the three directions of economic sustainability.

Table 7-9: Consolidate view on economic sustainability analysis at product level  
Source: Author-generated

| <b>Economic Sustainability Directions</b> | <b>Priority at product level</b> |
|---|----------------------------------|
| Sustaining Economic Growth                | 1 (very low)                     |
| Natural Capital Building                  | 4 (high)                         |
| Social and Human Capital Building         | 2 (low)                          |

#### *7.3.3.2. Lifecycle Level Analysis for Economic Sustainability*

At lifecycle level, the analysis attempts to explore how product’s lifecycle (here a mobile phone) influences the three directions of economic sustainability. The focus is on identifying opportunities in which product’s lifecycle could be improved for creating a positive impact on economic sustainability. Figure 7.10 illustrates the typical lifecycle of

a product in any economy. Product is first introduced in the market, its sale grows steeply, then at maturity stage its sales becomes stable and towards the end it starts declining marking the end of product's lifecycle.

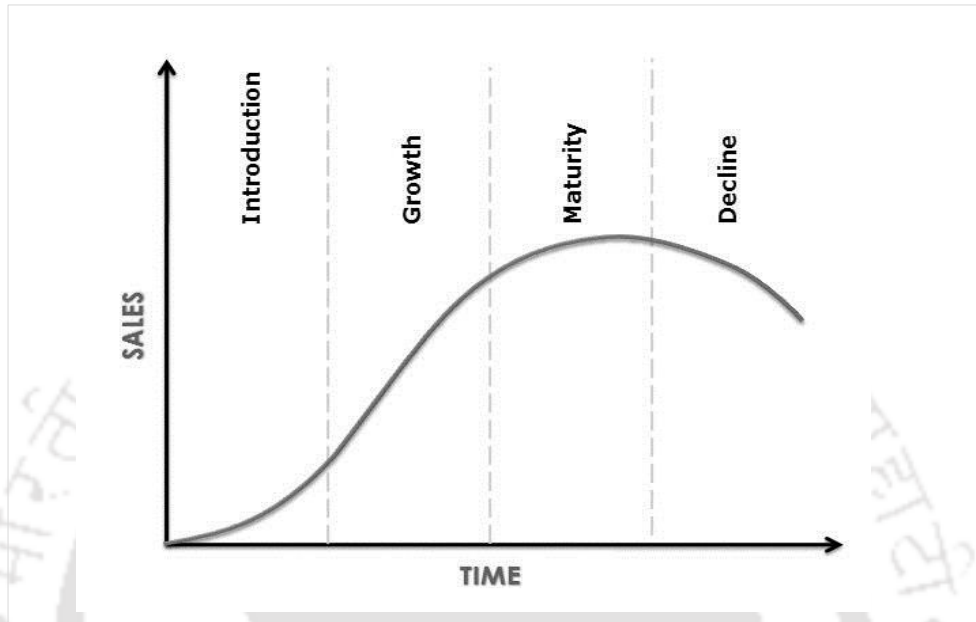


Figure 7.11: Typical lifecycle of a product in any economy

Source: Adapted from popular literature

### A. Sustaining Economic Growth

Products are designed and manufactured keeping in view the needs of the people and demand in the market. The sole objective of any product is to make a profit and sustain it for a very long time. For this purpose, the product lifecycle in the market (as shown in Figure 7.10) is optimised to make a profit, and contribute towards sustaining economic growth. To achieve it, different mobile phone manufacturers adopt different strategies for luring various consumer segments.

One of the strategies adopted by mobile phone manufacturers is to make the consumer buy more through planned obsolescence. Moreover, luring customers through constant improvement of phones with new features, and enforcing it through advertisements leads to high profit. However, this strategy encourages high discard rate of mobile phones and is in contrast with sustainability directions like building natural capital and environmental sustainability. Manufacturers need to find innovative ways in which the economic growth is sustained, at the same time it complements natural capital building and environmental sustainability. Owing to these reasons this direction of sustainability is rated 'high' on priority.

## B. Natural Capital Building

Building natural capital needs efficiency (such that no wastage of resources happens and no harm is caused to ecology & environment) throughout the mobile phone lifecycle starting from the introduction in the market to decline.

However, the high discard rate owing to shorter mobile phones' lifecycle (as discussed in the previous section) and lack of efficient end of life strategy (decline stage) adopted by manufacturers are a threat to natural capacity building. Owing to this 'high' priority is given to this direction of economic sustainability.

## C. Social and Human Capital Building

Mobile phone lifecycle, in general, has a positive effect on the social and human capital building, and that's why it is rated 'low' on priority. Table 7-10 presents the consolidated priority rating at lifecycle level for the three directions of economic sustainability.

Table 7-10: Consolidate view on economic sustainability analysis at lifecycle level

Source: Author-generated

| Economic Sustainability Directions | Priority at lifecycle level |
|------------------------------------|-----------------------------|
| Sustaining Economic Growth         | 4 (high)                    |
| Natural Capital Building           | 4 (high)                    |
| Social and Human Capital Building  | 2 (low)                     |

### 7.3.3.3. System Level Analysis for Economic Sustainability

At the system level, the economic sustainability analysis attempts to explore how product-service systems of mobile phones affect the three directions of economic sustainability. It also attempts to identify opportunities in which mobile phone systems can contribute to economic sustainability. In recent times, the mobile phone has become an important part of many systems concerning economic aspect, for example, mobile banking, m-commerce etc. Exploring all such systems is beyond the scope of this thesis. However, the following section elaborates on the effect of few mobile based systems on economic sustainability for demonstration purpose.

#### A. Sustaining Economic Growth

Mobile phone based systems like mobile banking; m-commerce etc. is known to have a positive effect on the economic growth. These systems provide easy access to different systems in an efficient and convenient manner, reducing the time constraints. For example - mobile-based banking services, mobile based payment services, etc. in recent

future will significantly increase, and is expected to contribute to sustaining economic growth especially in under-developed and developing nations.

Owing to the huge opportunity of mobile phone system towards economic sustainability, it is rated 'high' on priority.

### **B. Natural Capital Building**

Mobile phone based system is known to have a positive effect on natural capital building and is rated 'low' on priority. For example, m-commerce has reduced load from physical spaces, outlets and commuting of customers.

### **C. Social and Human Capital Building**

Mobile phone based systems have been known for social and human capital building through various services offered by many institutions. Various types of systems with easy access through apps (applications) are known to help with easy access to information and knowledge. Considering the potential of mobile phone based system, it is rated 'high' in social and human capital building. Table 7-11 presents the consolidated priority rating at lifecycle level for the three directions of economic sustainability.

Table 7-11: Consolidate view on economic sustainability analysis at system level

Source: Author-generated

| <b>Economic Sustainability Directions</b> | <b>Priority at system level</b> |
|---|---------------------------------|
| Sustaining Economic Growth                | 4 (high)                        |
| Natural Capital Building                  | 2 (low)                         |
| Social and Human Capital Building         | 4 (high)                        |

### **7.3.4. Consolidated view of Sustainability Analysis**

This section presents the consolidated view of sustainability analysis conducted in section 7.3.1 (page 143); 7.3.2 (160), 7.3.3 (167) on the 10 directions for sustainability at product, lifecycle, and system level.

From figure 7-11, it can be observed that at product level, the directions of bridge social sustainability (refer section 4.3.3.2, page 72), building natural capital (refer section 4.3.3.2, page 72), developing environmental awareness (refer section 4.3.1.4, page 69) and maintain social sustainability (refer section 4.3.2.3, page 72) are of high priority and have great potential towards improving the sustainability of a mobile phones. These results are in contrast with surveyed literature where the focus of sustainability was on

sustaining resources, maintaining ecological systems, regulating environmental impact. This indicates the usefulness of the proposed morphological approach for sustainable designing. It forces creative designers to seek the issues that are not considered in other disciplines.

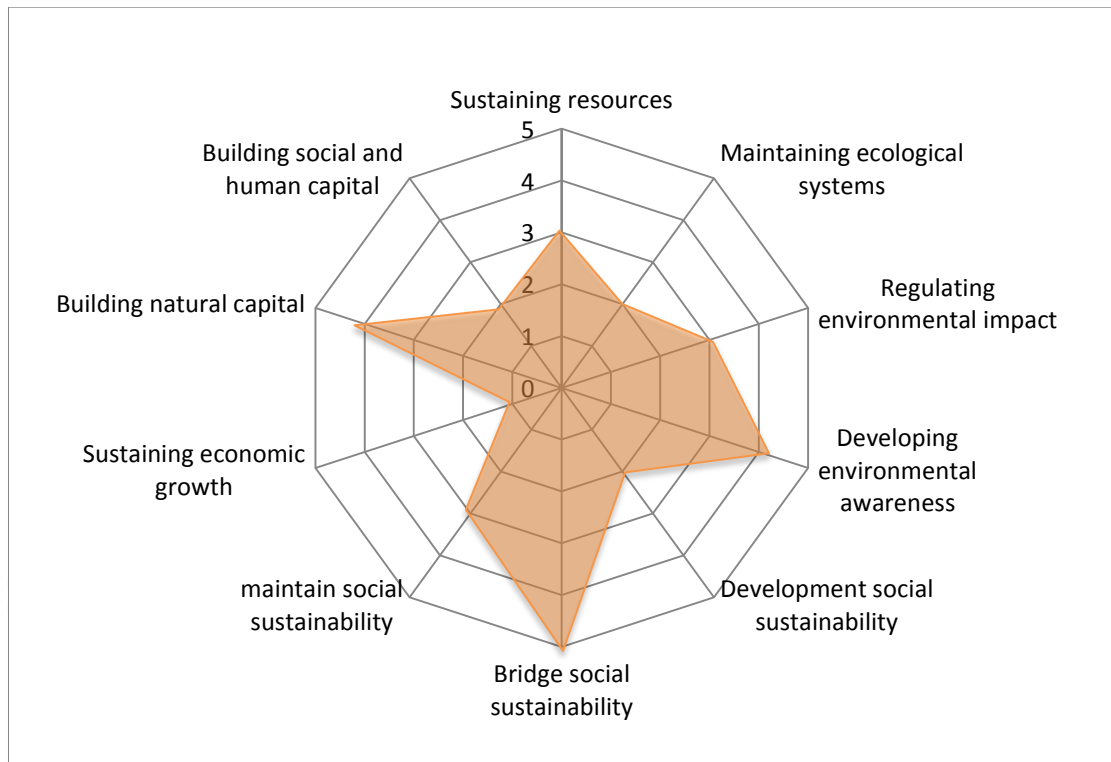


Figure 7-12: Radar to consolidate the findings of sustainability analysis at product level  
Source: Author-generated

From figure 7-12, it can be observed that at lifecycle level the directions of sustaining resources (refer section 4.3.1.1, page 67), developing environmental awareness (refer section 4.3.1.4, page 69), sustaining economic growth (refer section 4.3.3.1, page 76) and building natural capital (refer section 4.3.3.2, page 76) are of high priority. These directions of sustainability should be kept high on concern while designing lifecycle of a mobile phone.

From figure 7-13, it can be observed that at system level the directions of sustaining resources (refer section 4.3.1.1, page 67), building social and human capital (refer section 4.3.3.3, page 76), building natural capital (section 4.3.3.2, page 76) and sustaining economic growth (section 4.3.3.1, age 76) should be given high priority for sustainability.

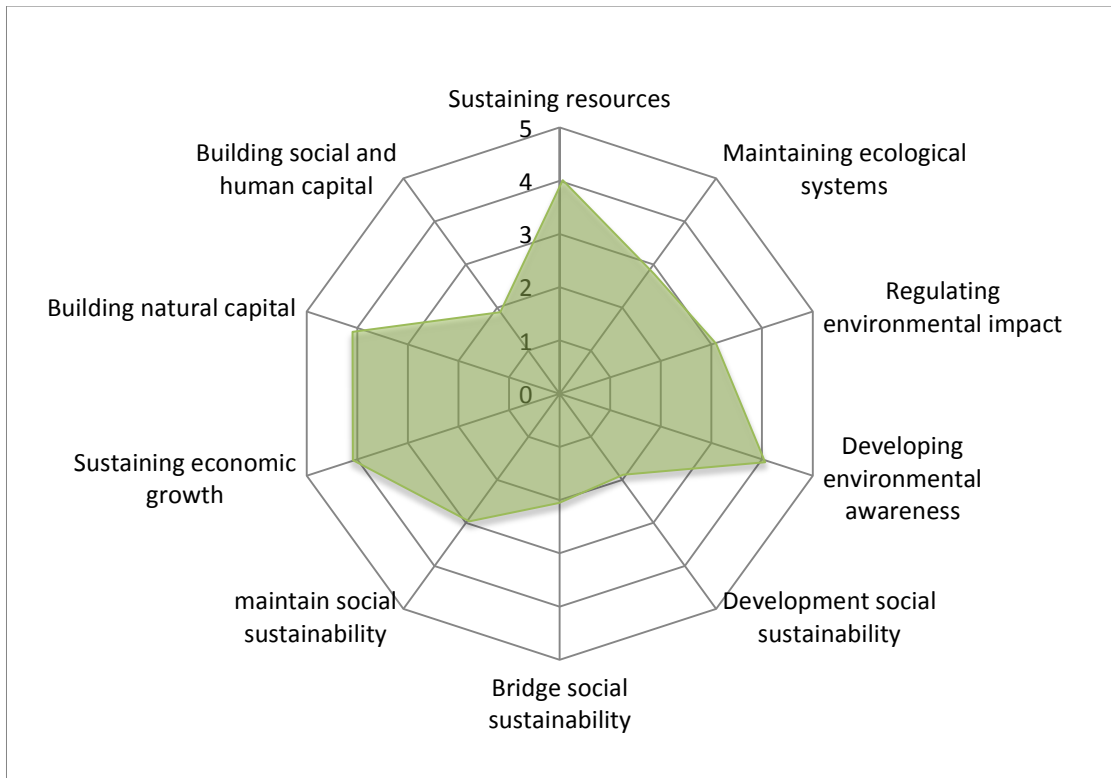


Figure 7-13: Radar to consolidate the findings of sustainability analysis at lifecycle level  
Source: Author-generated



Figure 7-14: Radar to consolidate the findings of sustainability analysis at system level  
Source: Author-generated

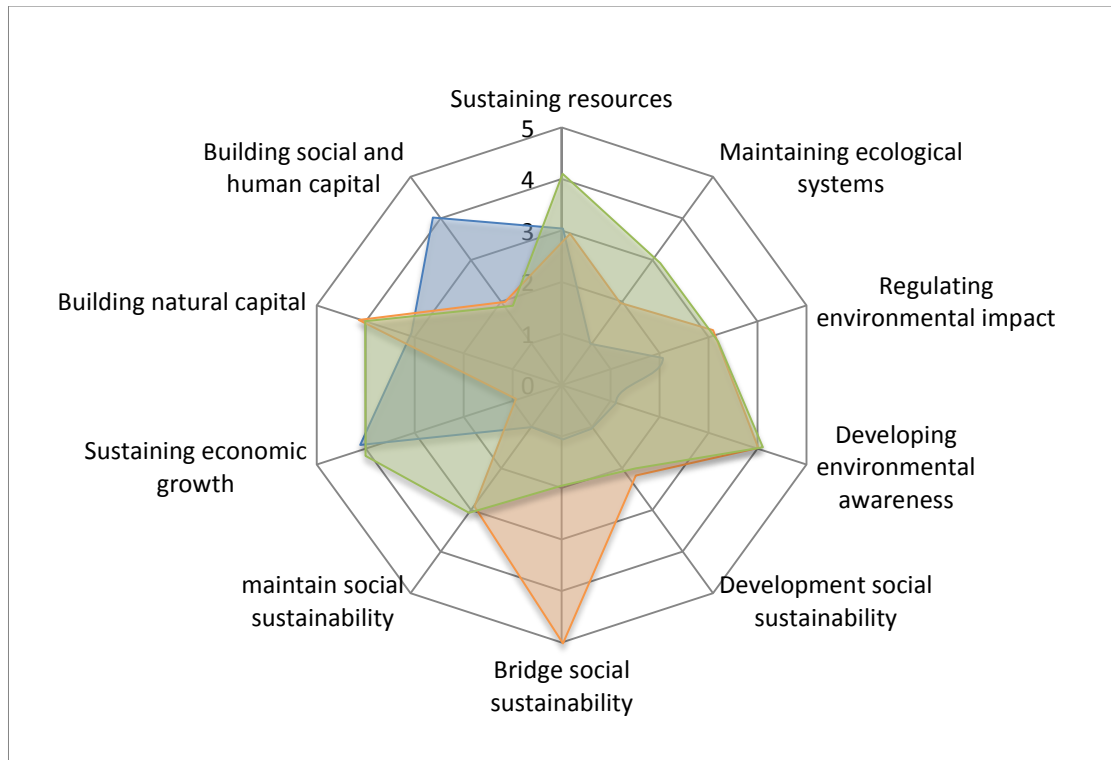


Figure 7-15: Radar illustrating the consolidated findings of sustainability at all the three level (blue-system level; green-lifecycle level and red-product level)

Source: Author-generated

Figure 7.14 plots the findings of sustainability analysis at all the three levels (product, lifecycle and system) and illustrates how certain directions of sustainability are high on priority at all the three levels. For example, developing environmental awareness is at a high priority at product and lifecycle levels. Similarly, sustaining economic growth is of high priority at lifecycle and system level. This type of radar plotting is expected to help designers in reflecting on their design related decisions.

From the above sustainability analysis of mobile phone, it can be observed that different sustainability directions may have a different level of priority at different levels (product- lifecycle- system). It also indicates that the variables of sustainability at one level (and hence its understanding), may change at the other levels and hence its implication will vary (depending on what level designer is working). Based on this analysis the following section presents the sustainability synthesis of the mobile phone.

#### 7.4. Sustainability Synthesis

As proposed in section 6.3.4 (page 135), synthesis for sustainability primarily consists of 2 activities – strategy formation and alternative solution creation (conceptualisation).

Figure 7.10 (page 172); figure 7.11 (page 173) and figure 7.12 (page 173) forms the basis of strategy formation. The strategy should be in the direction of sustainability direction that has high priorities.

For example, the direction of ‘developing environmental awareness’ at product and lifecycle levels were rated ‘high’ in priority during the analysis. Thus, the strategy should be on providing features and information at product and lifecycle levels that improves the environmental awareness.

Few of the possible concepts may be the development of visual graphics and interactive apps within the mobile phone that can sensitise and spread awareness. Providing information about the toxic nature of mobile phone components if not disposed properly and suitable e-waste collection systems will also raise environmental awareness.

Following are few of the other possible suggestion for increasing mobile phone sustainability:

1. Most mobile phones are discarded by their original users within 18 months. Once the mobile phone is discarded, most of them either lay ideal on the homes of the user or is dumped with the normal waste (Rathore et al., 2011). It means that most of the components are in good condition and can be reused. Low-end mobile phones can be designed using the discarded LCD screens and PCB/PWB components.
2. Facilitate the remanufacturing and refurbishing the high environmental impact components.
3. Making the PCB/PWB modular so that it can be reused in the low-end mobile phones by extracting the components like ICs.
4. Most of the mobile phones are discarded because users need to upgrade to technology and processing speed (Rathore et al., 2011). Designing mobile phones for upgradeability can be a promising approach.
5. Spread awareness among the users through mobile phone apps, graphics, etc. about the environmental impact of their mobile phones and how it can be avoided.
6. Design packaging that can be re-used and utilises renewable materials. Promote recycling of packaging.
7. Material Reduction – Reduce the amount of material that has low environmental sustainability at material extraction and processing stage.

8. Replace – Replace the material with a suitable alternative.
9. Recycling – Facilitate the recycling of materials that have low environmental sustainability.
10. Remanufacturing – Facilitate the remanufacturing of parts/components that uses materials with low environmental sustainability.
11. Re-use and refurbish – Facilitate the reuse and refurbishing of parts/components that use materials with low environmental sustainability. This knowledge can be used at the design stage in adopting appropriate strategies in minimising the impact.

| ↑ - complementary<br>↓ - conflicting<br>↑↓ - mutually complementary<br>↑↓ - contextual | Sustaining Resources | Maintaining ecological systems | Regulating environmental impact | Developing environmental awareness | Developmental social sustainability | Bridge social sustainability | Maintenance social sustainability | Sustaining economic growth | Building natural capital | Building social and human capital |
|--|----------------------|--------------------------------|---------------------------------|------------------------------------|-------------------------------------|------------------------------|-----------------------------------|----------------------------|--------------------------|-----------------------------------|
| Sustaining Resources   |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Maintaining ecological systems   |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Regulating environmental impact  |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Developing environmental awareness   | ↑                    | ↑                              | ↑                               |                                    |                                     |                              |                                   |                            |                          |                                   |
| Developmental social sustainability  |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Bridge social sustainability   | ↑                    | ↑                              | ↑                               | ↓                                  | ↑↓                                  |                              |                                   |                            |                          |                                   |
| Maintenance social sustainability  | ↓                    | ↓                              | ↓                               | ↑↓                                 | ↓                                   | ↑↓                           |                                   |                            |                          |                                   |
| Sustaining economic growth   | ↓                    | ↓                              | ↓                               |                                    | ↑                                   |                              | ↓                                 |                            |                          |                                   |
| Building natural capital   | ↑                    |                                | ↑                               | ↓                                  |                                     |                              |                                   | ↓                          |                          |                                   |
| Building social and human capital  | ↑                    | ↑                              | ↑                               | ↓                                  |                                     | ↑                            | ↑                                 | ↑↓                         | ↑                        |                                   |

Figure 7-16: Interaction matrix of sustainability directions based on the sustainability analysis of mobile phone

Source: Author-generated

At this point, the sustainability interaction matrix proposed in Section 4.3.4 (see Figure 4.6, page 78) will help in understating what other directions could be affected by the decisions made. If the relationship is complementary, then it will have a positive impact on sustainability, but if the relationship is conflicting then, the designer have to a trade-off between the two directions. Few such relationships in the context of the mobile phone as a sample product are illustrated in figure 7.15 for demonstration purposes.

Figure 7.15 demonstrated various possible relationships that need to be kept in mind which making the decision for improving the sustainability of a mobile phone. For example developing environmental awareness through visual graphics and interactive apps within mobile phone will complement directions of sustaining resources, maintenance ecological systems and regulating environmental impact.

The preference of users towards changing mobile phones based on fashion and technological trend, which they would like to be maintained, is in conflict with directions like sustaining resources, maintaining ecological systems and regulating environmental impact. However, this complements sustenance of economic growth. In such cases out of the box thinking is required for sustainable solutions. One such possibility is discussed in the following section.

#### 7.4.1. Religious Practice as a Tool for Sustainability

In literature, it was observed that there is general reluctance in people of India in donating their mobile phones for recycling (Yammiyavar & Kumar, 2011). There can be many reasons for this behaviour like lack of awareness about the hazardous effect of mobile phones, emotional attachment, perceived value in broken phones, etc. A designer could promote recycling by providing appropriate messages and graphics on the components indicating the dangers, mobile games and product information however, Yammiyavar & Kumar (2011) suggests the use of religious practice as a tool for phone collection.

In India, places of religious activity are also social networking hubs, and there is a popular culture of donation or offering at the place of worship. A possible solution for collecting discarded mobile phones can be a donation receiving box with a placard that asks for donating mobile phones (as shown in figure 7.16). Exploring such possibility of collecting used or discarded mobiles as a donation or offering at the place of worship can be a promising possibility.



Figure 7.17: Cash receiving box at a place of worship with placard (phone collection point)  
Source: (Yammiyavar & Kumar, 2011)

## 7.5. Validation through Empirical Study

The empirical validation of the proposed morphology was carried out by integrating it with the syllabus of a course on sustainable design. A set of two similar tasks (in the form of assignment) were given to students; one before the introduction of proposed sustainable design framework and one after introduction. The study of these two assignments submitted by students was expected to indicate the usefulness of the framework as well as the morphology.

### 7.5.1. Material and Methods

For empirically testing the usefulness of the proposed morphology of sustainable design, it was integrated with a course titled “*Introduction to the Philosophy of Sustainable Design*”. The course was a half semester long (20 hrs) course, open to undergraduate students (all disciplines) introduced at a Technical University in Uttar Pradesh (INDIA). The course intended to introduce the philosophy of sustainable design and its dimensions to students. It was expected to sensitize students towards sustainability and enable them to apply its fundamental principles in their day to day personal as well as professional life.

The syllabus of the course was structured in three parts (see Appendix 6 for detailed syllabus). The first part of the course briefly establishes the relationship of technology with society from a sustainability perspective and its significance in personal and professional life. The second part elaborated on the history and evolution of sustainable design through environmentalism, green design and eco-design and

introduced the existing popular models of sustainability. The third part of the course introduces the sustainable design framework and ten directions for sustainable design as an alternative to the established models of sustainability.

Two similar tasks in the form of assignment were given to the students. The first task was given after completing the first two parts of the course and the second one after the completion of part three. Keeping the course's low credit requirements in mind, the assignment was simplified by asking them to address sustainability issues only at lifecycle levels.

### 7.5.2. Participants and Study Location

The participants for the study were students of a technical university who chose the course '*Introduction to the Philosophy of Sustainable Design*'. A total 36 undergraduate students from different disciplines studying in the 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> year of their study participated. Table 7.12 shows the distribution of the participants.

Table 7-12: Distribution of participants for empirical study  
Source: Author-generated

| Discipline          | B. Tech. (all branches) |          |         | BSc<br>Economics | BA<br>English |
|---------------------|-------------------------|----------|---------|------------------|---------------|
|                     | II Year                 | III Year | IV Year |                  |               |
| No. of Participants | 12                      | 16       | 5       | 2                | 1             |

### 7.5.3. Method of Investigation

The study was conducted in three parts. At the starting of the course, data was collected regarding their understanding and prior knowledge of sustainability through a questionnaire (a snapshot shown in Figure 7.18).

After the completion of the first two parts of the syllabus, the first task (assignment 1) was given to participant (as discussed in Section 7.5.1). A similar task was given after the completion of the third part of the syllabus (which introduced the framework of sustainable design and its ten directions). These two tasks were given in a group of 2-3 students.

Name: Sakshi Yadav  
Degree (year): B. Tech. [ECE]- 2<sup>nd</sup> Year

- Have you ever attended any course/courses on sustainability/sustainable design/eco-design/green design? (Tick)  
Yes /  No
- Have you heard about these terms from sources apart from your studies?  
Yes /  No where: *sustainability was taught in EVS, and also in school.*
- According to your own understanding in 2-3 sentences define the term 'sustainability'.  
*Sustainability means to use a product or resource of any kind keeping in mind the importance of it in future.*
- What do you expect to learn from this course?  
*The course will make us aware of how we can actually sustain our resources and the basic points and strategies for that.*

Figure 7.18: A snapshot of the questionnaire  
Source: Respondent – generated

Following were the two tasks given to the students.

**Task 1:**

Select a simple product of your choice and explore its actual life cycle. Draw the lifecycle of the chosen product in the A2 size sheet provided to you. Detail out the sustainability impacting factors across different stages of its lifecycle. Please note that you are asked to explore the actual lifecycle, not the ideal one.

**Task 2:**

Identify any product of your choice, which has a scope of improvement on sustainability parameters. Explore its actual lifecycle stages and illustrate it with suitable diagrams. Based on the ten directions for sustainable design, identify the possible environmental, social and economic impacts at the various lifecycle stages. Based on your findings, prioritise the five most critical impacts and suggest ways in which it can be improved.

#### 7.5.4. Experimental Setup and Procedure

The students were giving the freedom of working on the tasks in their own time at the convenience place of work. For both the tasks, student was given the freedom of referring to any resources both online and off-line. Figure 7.19 illustrates the procedure followed by the study.

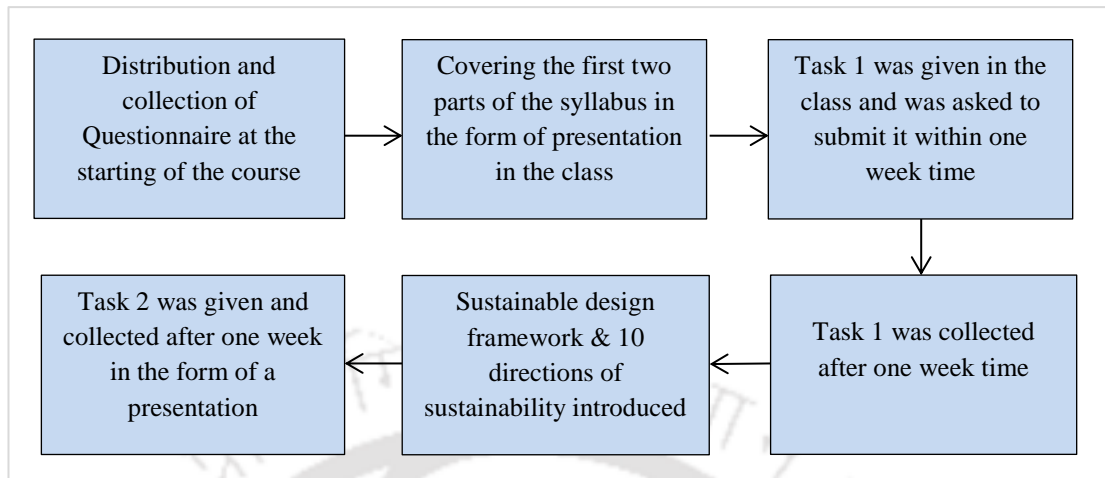


Figure 7-19: Procedure followed for data collection

Source: Author-generated

### 7.5.5. Analysis and Results

For questionnaire, descriptive statistics was used for analysis. For task 1 and 2, content analysis was done for extracting data and then was tabulated to infer results. Following were the main results of the analysis.

1. When asked whether they have ever attended any course/courses on sustainability/green design/eco-design 83% of the participants said 'No'.
2. When asked whether they have heard about the term sustainability/green design/eco-design 69% of the participant said 'Yes' (see Figure 7-20).

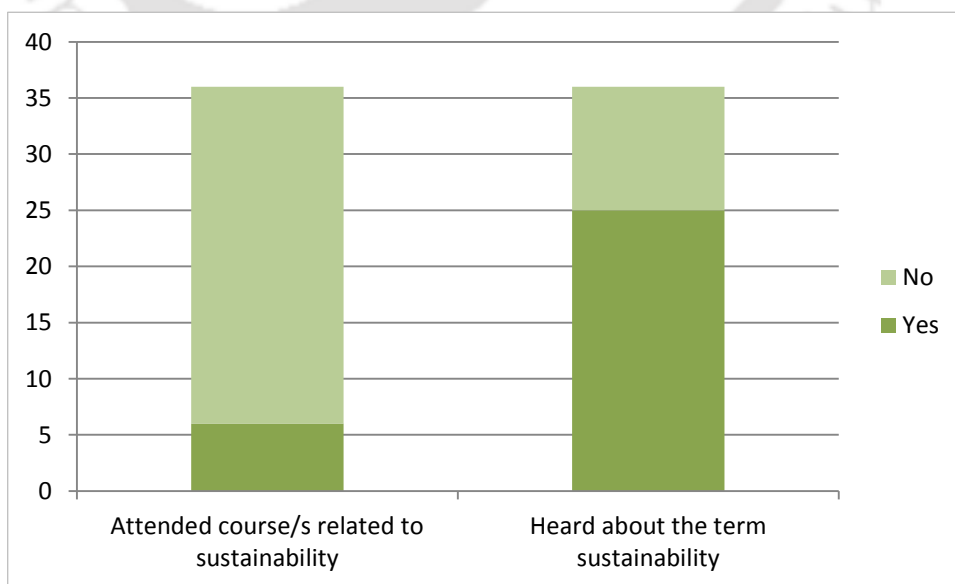


Figure 7-20: Procedure followed for data collection

Source: Author-generated

Table 7-13: sustainability impacting factors identified by participants for Task 1

Source: Author-generated

| Group | Products Chosen | No. of Sustainability Impacting Factors Identified |         |         |
|-------|-----------------|--|---------|---------|
|       |                 | Environment  | Society | Economy |
| G1    | Notebook        | 1  | 0       | 0       |
| G2    | Paper           | 7  | 1       | 0       |
| G3    | Pepsi Bottle    | 9  | 0       | 0       |
| G4    | Rubber Band     | 6  | 0       | 0       |
| G5    | ID Card         | 3  | 0       | 0       |
| G6    | Plastic Bag     | 6  | 0       | 0       |
| G7    | Glass Bottle    | 1  | 0       | 0       |
| G8    | News Paper      | 8  | 2       | 2       |
| G9    | Coin            | 3  | 0       | 0       |
| G10   | Aluminium Can   | 2  | 0       | 0       |
| G11   | Cotton Shirt    | 10   | 0       | 0       |
| G12   | Pet Bottle      | 3  | 0       | 0       |
| G13   | Woollen Cloth   | 1  | 0       | 0       |
| G14   | Plastic Bag     | 4  | 0       | 0       |

Table 7-14: Sustainability impacting factors identified by participants for Task 2

Source: Author-generated

| Group | Products Chosen        | No. of Sustainability Impacting Factors Identified |         |         |
|-------|------------------------|--|---------|---------|
|       |                        | Environment  | Society | Economy |
| G1    | Aluminium Water Bottle |  |         |         |
| G2    | Agro products          | 10   | 3       | 3       |
| G3    | Pencil                 | 6  | 2       | 3       |
| G4    | Toothbrush             | 7  | 2       | 1       |
| G5    | Pesticides             | 7  | 2       | 2       |
| G6    | Chips Packet           | 6  | 1       | 3       |
| G7    | Washing Machine        | 7  | 4       | 3       |
| G8    | Tyre                   | 15   | 4       | 2       |
| G9    | Solar Panel            | 2  | 3       | 3       |
| G10   | Plastic Products       | 2  | 3       | 1       |
| G11   | Wind Turbine           | 6  | 3       | 3       |
| G12   | LED                    | 15   | 5       | 2       |
| G13   | Vermi-compost          | 10   | 5       | 1       |
| G14   | Footwear               | 5  | 3       | 3       |

3. For task 1 all the students mentioned at least one 'environmental impacting factor across the lifecycle of the chosen product. However, only two participants mentioned social impact and none could mention any economic impact (see Table 7.13).
4. For task 2 all the students mentioned at least 2 environmental impacting factors (range 2-15), at least one social impact (range 1-5), and at least one economic impact (range 1-3) across the lifecycle of the chosen product (see Table 7.14).

Appendix 7 illustrates the the difference between the task 1 and task 2 completed by group 1, as an example.

### 7.5.6. Observations and Inferences

Following observations and inferences were made from the result of analysis discussed in Section 7.5.5.

1. Although most of the participants (83%) have never attended any course/courses on sustainability/green design/eco-design, 69% are aware of the term from sources other than studies. This is indicative of popularity of the philosophy across disciplines.
2. For task 1, all the participants have identified the environmental impacting factors (in the range of 1-10), but only two participants could come up with social impacting factors. This indicates that their understanding of sustainability is primarily focused towards environmental impact only.
3. For task 2 all the students mentioned at least 2 environmental impacting factors (in the range 2-15), at least one social impact (in the range 1-5), and at least one economic impact (in the range 1-3) across the lifecycle of the chosen product. This indicates that the sustainable design framework (with ten directions for sustainable design) and its morphology have assisted them in identifying more number of social and economic impacting issues. This may be an indication for the usefulness of the proposed morphology for sustainable design in contrast with the existing models of sustainability.

## 7.6. Verifying the Working Posit

The consolidated findings of sustainability analysis of mobile phone summarised in section 7.3.4 (page 171), demonstrate directions for increasing the sustainability of the mobile phone. Literature presents limited studies in these directions. This supports

working posit P3 which states that ‘a morphological approach for sustainable product designing reveals new directions for incorporating sustainability in design.

The empirical study reported in Section 7.5, shows an improvement in identifying sustainability impacting factors particularly in the social and economic dimensions. This also supports posit P3.

## 7.7. Conclusion

This chapter validates the proposed morphology of sustainable design. It demonstrates the morphology in action through dry run testing (using a mobile phone as a sample product) and an empirical study. The sustainability analysis of mobile phone revealed new directions in which the product has potential for improvement, as summarised in section 7.3.4 (page 171). Literature presents limited studies in these directions for sustainability that supports posit P3. The empirical study reflects that the proposed morphology have helped participants in identifying more number of sustainability issues especially in the social and economic dimensions.

The chapter also demonstrates how the use of proposed sustainability interaction matrix within morphology of sustainable design reveals the conflicting nature of sustainability directions (refer section 7.4, page 171). This is expected to help creative designers in design decision making related to sustainability issues.

The page features a large, faint watermark of the Indian Institute of Technology Guwahati logo. The logo is circular and contains the text 'Indian Institute of Technology Guwahati' in English and 'भारतीय प्रौद्योगिकी संस्थान गुवाहाटी' in Hindi. In the center of the logo is a stylized emblem consisting of three interlocking circles.

## Chapter 8

### Discussion and Conclusion

This chapter summarizes the major findings and core contributions of this research. It also highlights the limitations and general implications of the results in practice. The chapter also elaborates on the future scopes and potential paths of this research.

## 8.1. Introduction

This chapter intends to summarise the main research findings and core contributions of this research along with its general implication in practice, limitations and future scope. At first, main research findings are summarised in section 8.2. Section 8.3 presents the three core contributions of this research. Limitations and general implications of the research findings and contributions have been elaborated in Section 8.4. Section 8.5 discusses the future scope and potential directions for future research.

## 8.2. Main Research Findings

This research builds on the recently evolved consensus (among researchers, designers, manufacturers, etc.) of integrating the philosophy of sustainability with the practice of design. The main aim was to augment the understanding and practice of sustainable design from a creative designer perspective. The whole research was completed in three phases.

The first phase of the study was concerned with developing a comprehensive understanding of sustainable design and its dimensions, which was manifested in the form of a sustainable design framework. This phase covered research question RQ1 (and OB1) and was presented in chapter 4. The second phase was dedicated to understanding the existing practices of sustainable design and attempted to answer research question RQ2 and RQ3 (concerning OB2 and OB3). This phase explored the mental models and problem-solving approaches of novice creative designers towards sustainable design through an empirical study and was presented in chapter 5. The third phase of the study was concerned with research question RQ4 and RQ5. This phase of the study proposed a model of morphology for sustainable design and tested it. This morphology was proposed based on the inputs from phase 1 and phase 2 of the study. Chapter 6 presented the development of the proposed morphology and Chapter 7 presented its dry run test (using a mobile phone as a sample product) and empirical study. The following sub-section discusses the major findings from these three phases of research.

### 8.2.1. The Nature of Sustainable Design Philosophy

This finding was concerned with the first research question RQ1 (as stated on page 15). During literature survey it was found that the philosophy of sustainable design was

interpretative in nature with multiple definitions and varied understanding which largely depends on the field of study and area of application (as discussed in section 2.4, page 34). This situation was largely attributed to the different point of origin for this philosophy. On one hand it is seen to have evolved as a result of broadening of scope from earlier environmental conscious concept of green design and eco-design while on the other it is seen as a philosophy that resulted from the incorporation of sustainable development in design. This created a biased and interpretative understanding of sustainable design that was known to confuse creative designers about its implication in designing. Consequently, their approaches were often found to be limited in scope and biased.

This research establishes that both the points of origin have contributed to the comprehensive understanding of sustainable design. Sustainable development philosophy have brought in the three broad dimensions of environment (planet), society (people) and economy (profit) whereas, the broadening of scope from earlier environmental conscious concepts have highlighted the fact that these broad dimensions need to be applied at product, lifecycle and system levels. This finding was summarised in Figure 8.1, illustrating this broader understanding of sustainable design (derived based on analysis of literature from different perspectives).

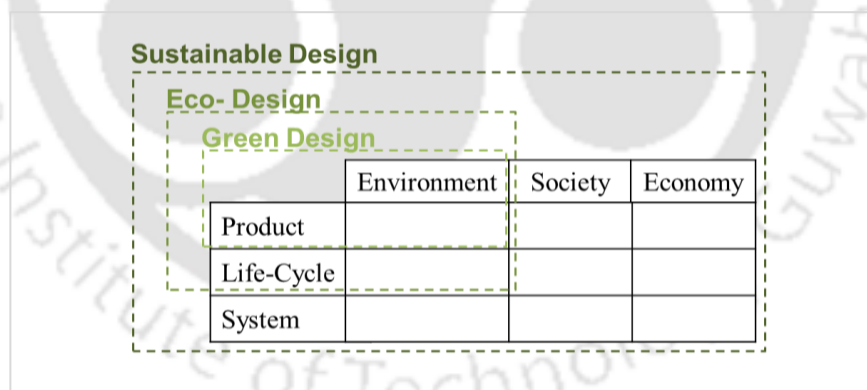


Figure 8-1: Sustainable Design – a comprehensive understanding (about related concepts)

Source: Author-generated based on analysis of literature

To make this philosophy more comprehensible in practice, a framework for sustainable design was proposed giving ten directions for sustainable design (discussed in section 8.3). This framework was expected to assist creative designers in understanding the comprehensive nature of sustainable design and applying it in their day to day practice of designing, which was one of the objectives of this research (OB1).

### 8.2.2. Sustainable Design Education in Indian Design Schools

Phase 2 of the study was concerned with answering RQ2 and RQ3 (page 16) and conducted an empirical study towards developing an understanding of mental models and problem solving approaches in the context of sustainable design (reported in chapter 5). During this study, a lack of sustainability philosophy integration with the design program of the surveyed institutions was observed. This finding has been discussed in section 5.4.1 point 1 and point 2 (page 114). This finding indicated that there is a need to reconsider the design program content for integrating sustainability philosophy in design education.

### 8.2.3. Existing Mental Models of Sustainable Design

Mental models are defined as internal symbol or representation of external reality and play a significant role in cognition, reasoning and decision making. Phase 2 of the study attempted to explore the perceptions and mental models of design students (novice designers) through an empirical study, reported in Chapter 5 (covering RQ2, OB2; page 16). The results of the study support posit P1 that the ‘existing perceptions and mental models of creative designers about the concept of sustainable design are biased towards environmental dimension’. This was reflected in the observation and inferences made in section 5.4.1 (page 114), point 4 & 5 (page 115) and section 5.4.2, point 2 (page 116).

This finding reveals that despite the broadening of scope and dimension of sustainable design (as found in 8.2.1), existing mental model of novice creative designers is still rooted in the environmental-conscious philosophies of design.

### 8.2.4. Existing Problem Solving Approaches for Sustainable Design

Section 2 of empirical study conducted in Phase 2 (reported in Chapter 5) of the research explored the problem solving approaches of novice designers given a sustainable design problem (concerning RQ3, OB3, page 16). This part of the study supported posit P2, which states that the “existing morphological approach of novice creative designers to sustainability given a sustainable design problem is through the environmental dimension”. This has been reported in section 5.4.2, point 2 (page 116).

In the study it was also found that 87% (21 out of 24) of the participants showed a morphological approach for solving the given problem, as reported in section 5.4.2, point 1 (page 115). Although, the morphological approach illustrated by the participants

closely corresponded with the traditional design morphology (as shown in figure 2.4, page 27), customization was made for incorporating sustainability aspect of the problem. This is likely due to the morphology-based method of imparting design education.

The study also found that the method of exploring sustainability issues in 76% (16 out of 24) participants were either random or semi-structured (refer section 5.3.2.2, point 2, page 112). Moreover, it was also observed that most of the explorations done by participants were focussed on environmental dimension only, and no prioritisation method was used for sustainability issues. This observation is likely due to the absence of a structured method of sustainability exploration and prioritisation known to them.

These observations about the problem-solving behaviour of novice designers indicated the need of a comprehensive morphology of sustainable design along with supporting methods of prioritisation and conflict resolution. Such morphology has been proposed in chapter 6 and is discussed in the following section.

#### 8.2.5. Limitation of Traditional Design Morphology

The empirical study conducted in Phase 2 of this research indicated that the traditional design morphology (as shown in figure 2.4, page 27) is of limited use in the context of sustainable design. In the response sheets of 87% (21 out of 24) respondents, it was observed that they diverted from the traditional morphology to add extra steps for exploring sustainability issues. These extra steps were added either after the problem definition phase (Type 2 methodology) or before the problem definition stage (Type 3 methodology).

These modifications done by respondents in the morphology reflects the requirement of improved morphology for sustainable designing. Section 8.3 illustrates an improved morphology for sustainable design that has been proposed in this thesis.

#### 8.2.6. Implications of the Proposed Morphology in Practice

In phase 3, the proposed morphology for sustainable design was dry run tested using mobile phone as a sample product. This was concerned with answering the research question RQ5 (OB5), and reported in chapter 7. The test revealed a new direction for improving the sustainability of mobile phones. Existing studies available in the literature on sustainability improvements of mobile phone was mainly dominated by environmental issues with issues like toxicity potential, material impacts, life cycle improvements, etc. A

limited number of studies is reported in the literature that covers the social sustainability aspect of a mobile phone.

The dry run testing of proposed sustainable design morphology showed ways in which the social aspect of sustainability can be improved. It also highlighted the contradictions of different directions of sustainability issues. These results indicate the usefulness of the derived directions for sustainability and the proposed sustainable design morphology.

### 8.3. Core Research Contributions

This research produces three core contributions to the field of sustainable design for creative designers. The following section elaborates on these contributions.

#### 8.3.1. A Comprehensive Framework for Sustainable Design

The understating of sustainability is contested in the literature that reflects varied understating and interpretations. This situation often confuses a creative designer in understanding what interpretations to be followed and what will be its implication. Moreover, owing to deep rooting of the philosophy of environmentalism, green design, eco-design there is a general bias among designers towards the environmental dimension of sustainability. This has been prominently reflected in the empirical study reported in Chapter 5 (concerning RQ2 and RQ3).

In the background of existing literature, this research derived a comprehensive understanding of sustainable design (concerning RQ1) and reported in chapter 4. To make this understanding more comprehensible a sustainable design framework was developed with ten directions for sustainability that can be applied at product, lifecycle and system levels (as shown in figure 8.2). These ten directions provide soft information about sustainability issues which according to Collado-Ruiz & Ostad-Ahmad-Ghorabi (2010), is most suited for creative designers (refer section 2.5.2 page 45).

This comprehensive framework of sustainable design is expected to assist creative designers (especially novice ones) in sustainability issue exploration and conceptualisation. It is also expected to help novice designers (under training) in building a better understanding and mental model of sustainable design.

| Directions for sustainability covering dimensions | Different levels at which sustainability impacting factors operate  |   |   |
|---|---|---|---|
|   | Product-level   | Lifecycle level   | System level  |
| Sustaining Resources                              | Resources consumed in manufacturing the modules/parts of product like energy and materials  | Resources consumed at different stages of the lifecycle like land, water, energy, etc.  | Resources that bring/will be consumed due to products effect on the system.   |
| Maintaining ecological systems                    | Parts/modules having potential of affecting the ecological systems and causing irreversible changes                                   | Lifecycle stages are causing irreversible changes like biodiversity loss, ecological cycle's disturbance, etc.  | Factors that affect the system impact on ecological systems   |
| Regulating environmental impact                   | Toxic and hazardous substances waste, generally reversible.   | Lifecycle phases where production of toxic and hazardous substances, waste.   | System in production of environmental impact like toxicity production, waste generation                             |
| Developing environmental awareness                | Lack of information which can be helpful for the decision makers  | Lifecycle stages where information is most needed for environmental friendly decision-making  | Information availability lead to environmental friendly decision making within the system                           |
| Developmental social sustainability               | Product and its use that influences the fulfilment of basic and higher-order needs  | Fulfilment of basic and higher order needs of stakeholders at different stages of the lifecycle   | System-level factors affecting the fulfilment of basic needs and higher order needs.                                |
| Bridge social sustainability                      | User behaviour while using the product is leading to wastage of resources, disturbance in ecology, etc.                               | Stakeholders' behaviour at different lifecycle stages of the product is leading to wastage of resources, disturbance in ecology.  | Stakeholders' behaviour is leading to wastage of resources, disturbance in ecology at system level                  |
| Maintenance social sustainability                 | Affecting the user preferences that they would like to be maintained like traditions, cultural preferences, religious practices, etc. | Stakeholders' preferences that they would like to be at different life cycle stages of product  | Stakeholders' preferences that they would like to be maintained are affected within the system                      |
| Sustaining economic growth                        | Products' features that do not add value to the producer and consumer - identify features that add value                              | Factors that has potential of increasing the products value for the customer as well as producer across the lifecycle stages  | Factors that can strengthen the product's market position, competition and future long-term business opportunities. |
| Building natural capital                          | Product features that the not efficient and has a potential of improvement contributing to resource efficiency                        | The factors that are not efficient across the lifecycle stages and leads to wastage of resources harms environment and ecology  | Factors that are not efficient and leads to wastage of resources, - opportunity for efficient technologies          |
| Building social and human capital                 | Product features that have potential of building competencies among user by providing information, knowledge                          | Factors across product's lifecycle (introduction, growth, maturity and decline) that have potential of building competencies among user by providing information, knowledge | System that are affected by the product building social and human capital   |

Figure 8.2: Comprehensive framework of sustainable design

Source: Author-generated

### 8.3.2. Interaction Matrix of Sustainability Directions

The second major contribution of this thesis (concerning RQ1) is the interaction matrix of sustainable design reflecting inter and intra dimensional relationship (see figure 8.3). This matrix provides four different types of relationships among the ten directions of sustainability. Such a matrix is expected to help creative designers in understanding the implications of their design decisions on other dimensions of sustainability.

| ↑ - complementary<br>↓ - conflicting<br>↑↓ - mutually complementary<br>↑↓ - contextual | Sustaining Resources | Maintaining ecological systems | Regulating environmental impact | Developing environmental awareness | Developmental social sustainability | Bridge social sustainability | Maintenance social sustainability | Sustaining economic growth | Building natural capital | Building social and human capital |
|--|----------------------|--------------------------------|---------------------------------|------------------------------------|-------------------------------------|------------------------------|-----------------------------------|----------------------------|--------------------------|-----------------------------------|
| Sustaining Resources   |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Maintaining ecological systems   |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Regulating environmental impact  | ↑                    | ↑↓                             |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Developing environmental awareness   | ↑                    | ↑                              | ↑                               |                                    |                                     |                              |                                   |                            |                          |                                   |
| Developmental social sustainability  |                      |                                |                                 |                                    |                                     |                              |                                   |                            |                          |                                   |
| Bridge social sustainability   | ↑                    | ↑                              | ↑                               | ↑↓                                 | ↑↓                                  |                              |                                   |                            |                          |                                   |
| Maintenance social sustainability  | ↓                    | ↓                              | ↓                               | ↑↓                                 | ↓                                   | ↑↓                           |                                   |                            |                          |                                   |
| Sustaining economic growth   | ↓                    | ↓                              | ↓                               |                                    | ↑                                   |                              | ↓                                 |                            |                          |                                   |
| Building natural capital   | ↑                    |                                | ↑                               | ↑↓                                 |                                     |                              |                                   | ↓                          |                          |                                   |
| Building social and human capital  | ↑                    | ↑                              | ↑                               | ↑↓                                 |                                     | ↑                            | ↑                                 | ↑↓                         | ↑                        |                                   |

Figure 8.3: Interaction matrix of sustainable design directions

Source: Author-generated

The empirical study reported in chapter 5 reflected a lack of clear understating among designers regarding the effect of their design decisions taken to improve one dimension of sustainability on the other dimensions (refer section 5.4.2, point 3, page 116). The proposed sustainability matrix is expected to make creative designers aware of

the implications of their design decisions. It is expected to assist them in taking a more conscious and informed decision. The matrix is also expected to help designers in understating the point of conflicts and will help them in coming up with innovative solutions through conflict resolution.

### 8.3.3. Morphology for Sustainable Design

The third major contribution of this thesis is the proposed model of sustainable design morphology for creative designers (concerned with RQ4, page 16) as shown in figure 8.4. This morphology is expected to provide a methodological approach to designing for sustainability that was one of the research gap identified in section 2.6.3 (page 49). It recommends that the most suitable point of considering sustainability is during the creative design phase (consisting of analysis, synthesis and evaluation). It also includes the visualisation and evaluation tool for sustainable design.

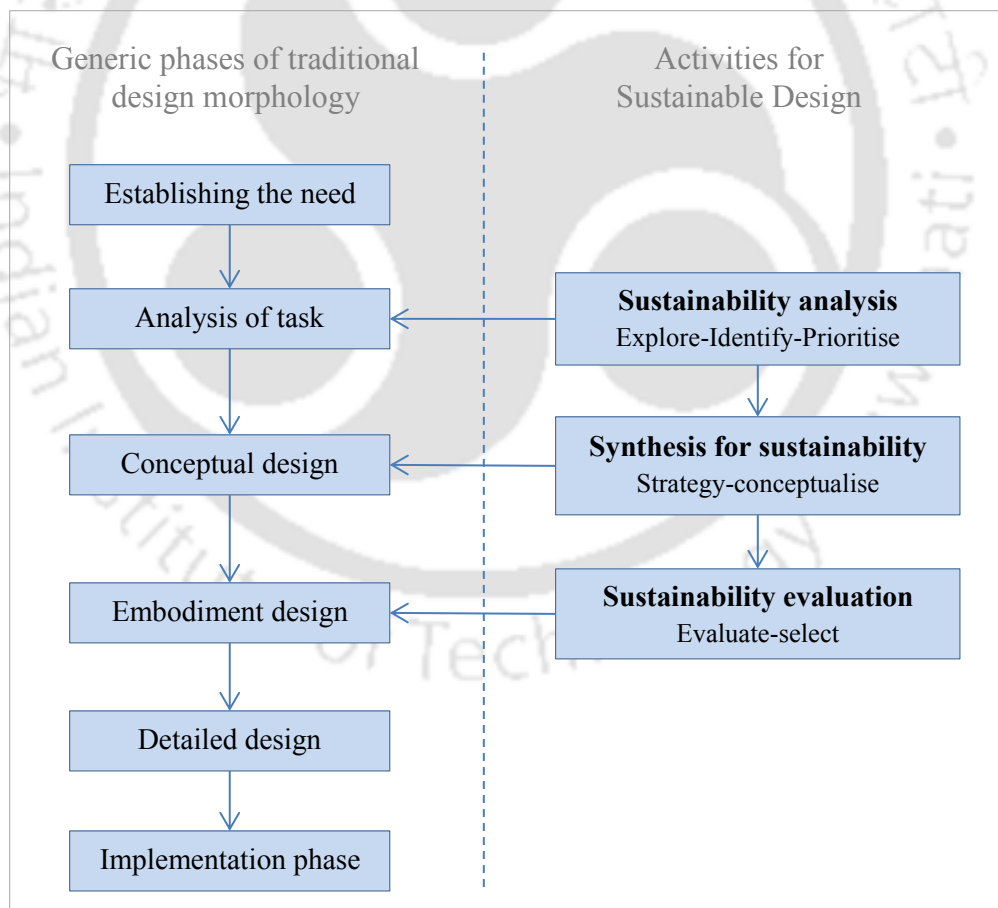


Figure 8.4: Proposed model of morphology for sustainable design

Source: Author-generated

## 8.4. Limitations and Generalisations of this Research

This section attempts to highlight the limitations and generalisations that can be made from this research.

### 8.4.1. Limitations of this Research

Following are the major limitations of this research:

1. The empirical study towards exploring the perceptions, mental models and problem-solving approaches of novice designers towards sustainability and sustainable design (reported in chapter 5 concerning RQ2 and RQ3) was conducted with a limited sample (owing to qualitative nature of the study). It was conducted only in three design schools from northern and eastern part of India with 70 participants. The results of this study should thus be carefully used for any generalisation. There is a possibility that students of other design schools may not show the same mental model and problem-solving behaviour.
2. The empirical study involved only Indian design schools and students, and thus its generalisation in a cross-cultural context should be made with care. Culture may have a significant effect on the perceptions and mental model of designers. Moreover, these mental models guide the problem-solving approaches of designers that are likely to affect their approach towards sustainability.
3. The framework of sustainable design (derived in chapter 4, concerning RQ1) proposed ten directions for sustainability. Although the intention was to make it as comprehensive as possible (by considering definitions and understanding from varied disciplines), however considering the evolving nature of sustainable design there is a possibility that few aspects might not have been covered by these directions.
4. The sustainability interaction matrix (refer figure 8.3) highlights on four general types of relationships. Depending on the product to be designed and context of use there is a possibility of more types of inter and intra dimensional relationships. Moreover, inter and intra dimensional relationships presented in this thesis are generic in nature and may have some exception depending on the problem at hand.
5. The proposed morphology of sustainable design (proposed in Chapter 6 concerning RQ4) was not tested exhaustively with control group experiments. Although it was tested through a dry run, and empirical study the actual behaviour of designers while

using this morphology along with sustainable design framework and interaction matrix cannot be fully predicted. For fully reflecting on the usefulness of the results one need to test it on a live project with practicing designers.

6. The presentation format of the proposed methodology while training novice designers was beyond the scope of this thesis and is another limitation of this thesis. The presentation format (like software application, a brochure, presentation, etc.) of the proposed sustainable design framework and morphology is likely to affect the learning curve of designers.

#### 8.4.2. Generalisations of this Research

The following generalisation can be made from the findings of this research.

1. Assuming, that the condition of design schools across India is same as that of surveyed institutions, it can be generalised that there is a lack of sustainability integration within the design programs, and appropriate steps need to be taken in this direction.
2. The biased mental model of novice designers as observed in the empirical study reported in Chapter 5 and extensively observed in the literature towards the environmental dimension is likely to be a general trend, especially in case of engineering design. Considering this trend the ten directions for sustainability can be used by anyone who is involved in sustainability business. These ten directions are very generic in nature and seem to be useful for all the disciplines.
3. One of the general implications of this research is the limited use of traditional design morphology in the context of sustainable design. Traditional design morphology is still in practice for training novice creative designers. This research reflects that such morphology fails in assisting designers in incorporating sustainability issues and thus it should be used with caution for sustainable product designing.
4. The inclusion of cultural aspects in designing for sustainability (as reported in this thesis) although covers the Indian context. However, it is equally valid for any other culture or any other part of the world. The approach may vary from culture to culture for example donation for charity, donation for building a church, etc.

5. The developed framework and morphology for sustainable design was developed keeping in concern the perception and mental model of creative designers. However, it can be very easily used by people from other disciplines. For example engineering designers approach to designing is generally problem-centric and is focussed on issues like efficiency, materials, assembly, manufacturing, etc. The ten direction for sustainable design may reveal how culture, for example, can be used as a tool to increase the sustainability of their products.

### 8.5. Scope of Future Research

There can be three major scopes of future research concerning the study of morphological approach towards sustainable product designing.

#### 8.5.1. Refining the Sustainable Design Framework

One of the possible directions for future research is towards the refinement and improvement of the proposed framework of sustainable design. The proposed directions of sustainability can be empirically tested to find out contradictions in understanding and accordingly be refined. Moreover, if there are more directions that have not been accommodated, it should be explored and added.

#### 8.5.2. Further Exploration in Practice of Sustainable Design

This thesis presents the exploration of perceptions and mental model of novice designers and their approaches towards sustainable design. The study can be further extended and elaborated by increasing the number of samples, comprising the approach of two groups of designers of different nations, implications of culture on the perception and approach of designers. It can be further extended to the exploration of problem-solving approaches of expert designers and industrial practices.

#### 8.5.3. Refining the Proposed Morphology of Sustainable Design

Refining and improving the proposed morphology of sustainable design can be another possible direction for future research. This thesis validated the morphology through dry run testing using only one product. However, it can be applied in multiple contexts for designing products from different categories. This is expected to direct on the limitations of the morphology, and can be very helpful in refining it.

Further investigation can be carried out towards the usability aspect of its presentation format. The morphology can be presented to students in many ways (like a brochure, software application, infographics, etc.) and tested for user preferences on usability parameters.

Based on the usability testing, a host of support tool can be developed supporting the proposed morphology.



## Appendix 1

### Dear Participant

**Thank you for volunteering and consenting to take part in this data collection exercise.** The data being collected here are part of an ongoing research which will help us in understanding the perceptions and conceptual maps of designers about the evolving philosophy of design for sustainability (DFS) (and sustainable design). Design for sustainability is now becoming imperative given the pressure from government and consumers for reducing resource consumption, pollution, and carbon footprints for any product to be manufactured. Creative designers have a huge potential role in contributing to sustainability of any product as they are the ones who conceptualise the product and makes decision on 60 to 80 percent of factors that affect sustainability. This research study-data collection exercise is being conducted by the Department of Design- IIT Guwahati. We are trying to understand how and when sustainability variables (factors affecting sustainability of a product) are influencing the designer's thought process regarding Design Methodology. We wholeheartedly thank you for your cooperation and valuable time. **Please respond to the following questions as honestly and carefully as possible.**

Vikash Kumar, Research Scholar, DoD IITG, [vikash.k@iitg.ac.in](mailto:vikash.k@iitg.ac.in)  
(Supervisor: Prof. Pradeep G. Yammiyavar, DoD, IITG)

Name (optional): .....

Gender: ..... Age:.....

E-mail id: .....(Required for clarification, if necessary)

### Section 1

**The main objective of this section is to comprehend your understanding and perception about the concept of 'Sustainable Design'.**

1. Please fill in the table below:

|                                 | Degree name with discipline | Name of the university or institution |
|---------------------------------|-----------------------------|---------------------------------------|
| Currently enrolled in           |                             |                                       |
| Last degree completed ( if any) |                             |                                       |

2. Number of years you are associating yourself with the discipline of 'Design' (including academics and work experience). .....yrs.
3. Did your current degree have any course/courses related to sustainability in design? (Circle one) Yes/No
4. Have you attended any conference/workshop/seminar/short-term course/symposium etc. related to 'Design for sustainability' in the last four years? (Tick) Yes/No
5. In two or three sentences, describe your understanding of 'sustainability' in terms of the following perspectives. If your answer is the same in all cases mentioned below, please write 'same'.

As a creative product designer -----

-----  
 -----  
 -----  
 -----  
 -----

As a user of a hired taxi-----

-----  
 -----  
 -----  
 -----

As a citizen of the country-----

-----  
 -----  
 -----  
 -----

As a universal human being-----

-----  
 -----  
 -----  
 -----

6. Various terms/words are associated with the concept of DFS, including green design, eco-design, environmental design, etc. (see below). Put a check mark (✓) beside the terms which you are familiar with. Please list any other words/terms associated with sustainable design that are not shown here in the blanks provided at the end of the list. Then, rate each of them (%) according to their influence on product sustainability. Shade the boxes as shown in the example.

Example:

|                | Ratings (in percentage) |    |    |    |    |    |    |    |    |    |     |
|----------------|-------------------------|----|----|----|----|----|----|----|----|----|-----|
| Terms/ words   | 0                       | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| XYZ Design (✓) |                         |    |    |    |    |    |    |    |    |    |     |

|              | Ratings (in percentage) |    |    |    |    |    |    |    |    |    |     |
|--------------|-------------------------|----|----|----|----|----|----|----|----|----|-----|
| Terms/ words | 0                       | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Green design |                         |    |    |    |    |    |    |    |    |    |     |
| Eco-design   |                         |    |    |    |    |    |    |    |    |    |     |

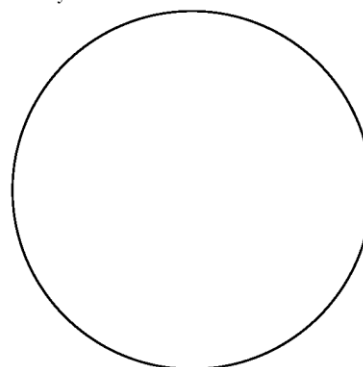
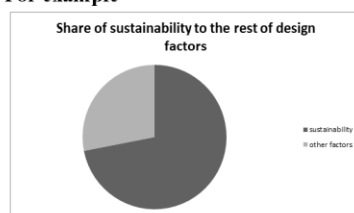
|                                    | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|------------------------------------|---|----|----|----|----|----|----|----|----|----|-----|
| Design for environment             |   |    |    |    |    |    |    |    |    |    |     |
| Carbon footprint                   |   |    |    |    |    |    |    |    |    |    |     |
| Ecological footprint               |   |    |    |    |    |    |    |    |    |    |     |
| Design for sustainable development |   |    |    |    |    |    |    |    |    |    |     |
| Design for disassembly             |   |    |    |    |    |    |    |    |    |    |     |
| Design for cleaner production      |   |    |    |    |    |    |    |    |    |    |     |
| 1.                                 |   |    |    |    |    |    |    |    |    |    |     |
| 2.                                 |   |    |    |    |    |    |    |    |    |    |     |
| 3.                                 |   |    |    |    |    |    |    |    |    |    |     |

7. Self-evaluate your knowledge about the concept of ‘Sustainable Design’.

| novice | beginner | competent | proficient | expert |
|--------|----------|-----------|------------|--------|
|        |          |           |            |        |

8. Designers are supposed to consider many factors while designing; some of them are ergonomics, aesthetics, function, manufacturing, etc. In recent years, sustainability has become one more factor to be considered while designing. Please assess the importance of product sustainability in relation to other factors by including it as a variable in the blank pie chart. Please give this matter some thought; then, complete the chart with your assessment of the importance of sustainability variable to the rest of the variables.

**For example**



9. Please describe how your education program’s curriculum equipped you to incorporate sustainability principles into your professional work.

| not at all | somewhat | quite a bit | sufficient | a great deal |
|------------|----------|-------------|------------|--------------|
|            |          |             |            |              |

10. Are you as a consumer willing to pay more for a product that fulfils the norms of sustainable/eco-friendly/environment friendly?

| never | sometimes | often | always | not sure |
|-------|-----------|-------|--------|----------|
|       |           |       |        |          |

11. Name any product that you are using/used recently/bought that reflects the manufacturer's consideration of sustainability.

(a) Name of product: ..... (b) Cannot recollect.

12. In your opinion, how sustainable are the products shown below? Rate them on a scale of 1 to 10 where 1 means 'Unsustainable' and 10 means 'Ideally sustainable'.

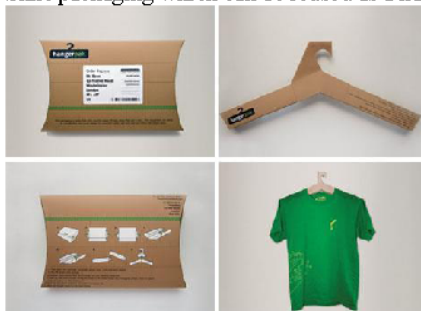
a. Bottle made of paper



|   |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|---|---|---|----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|----|

Extended Comments-----  
 -----  
 -----  
 -----  
 -----  
 -----  
 -----  
 -----

b. Shirt packaging which can be reused as a hanger



|   |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|---|---|---|----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|----|

Extended Comments-----  
 -----  
 -----  
 -----  
 -----  
 -----  
 -----

c. Tata Nano Car



|   |   |   |   |   |   |   |   |   |    |
|---|---|---|---|---|---|---|---|---|----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|----|

Extended Comments-----  
 -----  
 -----  
 -----  
 -----  
 -----

## Section 2

This section comprises a design problem. The brief is given below. Sketch and explain your design solutions/concept in the sheet provided to you. Try to generate as many concepts as possible within the given time. The main aim of this section is to understand how you as a designer approach sustainability-related issue in a design problem and what methodology you follow. It is an attempt to understand how you incorporate sustainability aspects while you conceptualise/solve a design problem. It does not intend to either evaluate you or your proficiency and skills as a designer. It is an attempt to capture your mental models of incorporating sustainability based on your respective level. **The end result of your output should take into consideration sustainability as an equally important parameter along with other aspects such as aesthetics, ergonomics, function, feasibility of final solution, etc.** A high quality rendering/sketch is not desired; the sketch simply needs to be at a level to communicate the concept. You are advised to go through Appendixes A and B before beginning the conceptualisation, filling them in as you solve the problem and generate the concept. **Please feel free to ask any questions that come to your mind.** Given below is the problem statement.

### Problem Statement

A mobile phone (also called cellular phone, cell phone or hand phone) is a two-way radio, which sends and receives radio signals, carrying voice and data in personal communication with other mobile phones and telephones (Nokia, 2005). The traditional mobile phones were used only for voice transmission but modern mobile phones also support a wide variety of other services such as text messaging, MMS, email, internet access, short-range wireless communications (infrared, bluetooth), business applications, gaming and photography. In the near future with development of technologies like cloud computing, mobile phones are expected to support more general computing and thus could be replacements for many more computing devices. The device is expected to support many new businesses and services, indicating its versatility (e.g. M-commerce, M-healthcare, and M-banking). These predictions suggest that the device is very important from the sustainability perspective.

Recent studies claim that mobile phones are not sustainable products. Few of the arguments given in its support are high obsolescence rate, consumption of toxic and rare materials, health effects etc. A few of the arguments, for example one study found that small-scale electronic devices like mobile phones have significant environmental impact which is distributed along its lifecycle as shown in the Figure1.1 below. The size of the box shows the amount of impact, which is maximum during use phase and minimum at end of life phase.

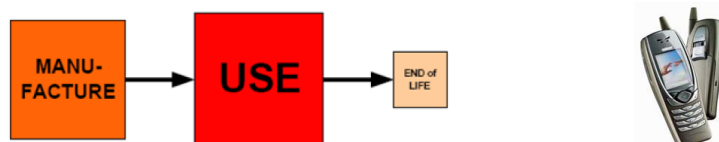
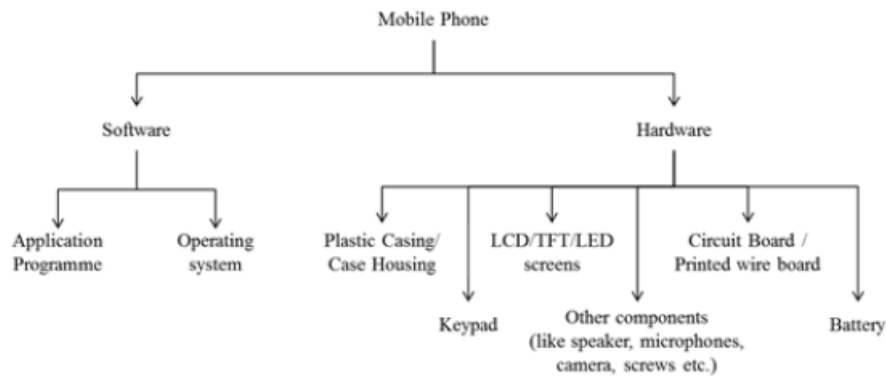


Figure 1.1: Environmental impact of mobile phones during different stages of life

A general classification of the parts of a mobile phone is shown in Figure 1.2.



**Figure 1.2: A general classification of components and parts of a mobile phone**

A dissected view of three mobile phones is shown in Figure 1.3 to give you an idea of what is under the shells. The three samples were priced differently, but they were produced by the same manufacturer. It can be observed that a mobile phone is structurally complex, with numerous components made of a variety of materials (Nokia, 2005).



**Figure 1.3: Dissected mobile phones of different price ranges**

You as a designer have been given the task of designing a mobile phone for urban youth who are in college like yourself. Since there is pressure from customers and the government to improve mobile phones from the perspective of sustainability, you have been given the task of conceptualising a sustainable mobile phone and suggesting necessary improvements. Briefly

explain the features in your concept (along with sketches) which can increase the sustainability of the mobile phones. Fill in Appendix A and B as you go along conceptualising such a mobile phone. You may use any design methodology/steps/sequence you may wish to adopt.

### Appendix A

In the table below please list the design variables that came across your mind while thinking of the concept of a sustainable mobile phone. You have to do a listing of the variables as they occur in your mind during conceptualisation.

A **design variable** is any *quantity* or *attribute* or *choice* directly under the control of the designer. In other words, a design variable is a specification that is controllable from the point of view of the designer. Therefore, for a coffee cup, some of the design variables may be height, material, colour, etc.

Now make a list of all the **Design Variables** that you have considered or should be considered while designing the solution i.e. a sustainable mobile phone. Many of these variables are likely to pop up as information required while you start conceptualising the mobile phone. Make a list of all the variables in the table below

| Sl no | Variables Name | Ratings from 1 to 10 (1= low, 10= high ) |   |   |   |   |   |   |   |   |    |
|-------|----------------|--|---|---|---|---|---|---|---|---|----|
|       |                | 1  | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|       |                |  |   |   |   |   |   |   |   |   |    |
|       |                |  |   |   |   |   |   |   |   |   |    |
|       |                |  |   |   |   |   |   |   |   |   |    |

### Appendix B

After finishing the exercises think about the steps/sequence/methodology which you have followed and draw a work flow diagram in the space provided. The researcher is interested in understanding how step by step you as a designer have gone around solving the problem. What you did first, then what you did next. If the sheet provided is not sufficient then draw it on a separate sheet and attach it. You don't have to be rigid in thinking. If you are not comfortable in making a work flow diagram then simply write it in steps. Feel free to ask any questions.

# Blank Space

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## Sheets for Conceptualisation

7

## Appendix 2

**Evaluator Code:**

**DD:** Un-decided  
**GD:** Green design

**ED:** Eco-design  
**SD:** Sustainable Design

| Subject   | No. of times words/phrases are used |         |         |    | Philosophy |                          |  |  |
|-----------|-------------------------------------|---------|---------|----|------------|--------------------------|--|--|
|           | Environment                         | Society | Economy | UD |            | Extreme preservationist  |  |  |
| Product   |                                     |         |         | GD |            | Resource preservationist |  |  |
| Lifecycle |                                     |         |         | ED |            | Resource conservationist |  |  |
| System    |                                     |         |         | SD |            | Resource exploitative    |  |  |
|           |                                     |         |         |    |            | Un-decided               |  |  |

| Subject   | No. of times words/phrases are used |         |         |    | Philosophy |                          |  |  |
|-----------|-------------------------------------|---------|---------|----|------------|--------------------------|--|--|
|           | Environment                         | Society | Economy | UD |            | Extreme preservationist  |  |  |
| Product   |                                     |         |         | GD |            | Resource preservationist |  |  |
| Lifecycle |                                     |         |         | ED |            | Resource conservationist |  |  |
| System    |                                     |         |         | SD |            | Resource exploitative    |  |  |
|           |                                     |         |         |    |            | Un-decided               |  |  |

| Subject   | No. of times words/phrases are used |         |         |    | Philosophy |                          |  |  |
|-----------|-------------------------------------|---------|---------|----|------------|--------------------------|--|--|
|           | Environment                         | Society | Economy | UD |            | Extreme preservationist  |  |  |
| Product   |                                     |         |         | GD |            | Resource preservationist |  |  |
| Lifecycle |                                     |         |         | ED |            | Resource conservationist |  |  |
| System    |                                     |         |         | SD |            | Resource exploitative    |  |  |
|           |                                     |         |         |    |            | Un-decided               |  |  |

| Subject   | No. of times words/phrases are used |         |         |    | Philosophy |                          |  |  |
|-----------|-------------------------------------|---------|---------|----|------------|--------------------------|--|--|
|           | Environment                         | Society | Economy | UD |            | Extreme preservationist  |  |  |
| Product   |                                     |         |         | GD |            | Resource preservationist |  |  |
| Lifecycle |                                     |         |         | ED |            | Resource conservationist |  |  |
| System    |                                     |         |         | SD |            | Resource exploitative    |  |  |
|           |                                     |         |         |    |            | Un-decided               |  |  |

| Subject   | No. of times words/phrases are used |         |         |    | Philosophy |                          |  |  |
|-----------|-------------------------------------|---------|---------|----|------------|--------------------------|--|--|
|           | Environment                         | Society | Economy | UD |            | Extreme preservationist  |  |  |
| Product   |                                     |         |         | GD |            | Resource preservationist |  |  |
| Lifecycle |                                     |         |         | ED |            | Resource conservationist |  |  |
| System    |                                     |         |         | SD |            | Resource exploitative    |  |  |
|           |                                     |         |         |    |            | Un-decided               |  |  |

| Subject   | No. of times words/phrases are used |         |         |    | Philosophy |                          |  |  |
|-----------|-------------------------------------|---------|---------|----|------------|--------------------------|--|--|
|           | Environment                         | Society | Economy | UD |            | Extreme preservationist  |  |  |
| Product   |                                     |         |         | GD |            | Resource preservationist |  |  |
| Lifecycle |                                     |         |         | ED |            | Resource conservationist |  |  |
| System    |                                     |         |         | SD |            | Resource exploitative    |  |  |
|           |                                     |         |         |    |            | Un-decided               |  |  |

| Subject   | No. of times words/phrases are used |         |         |    | Philosophy |                          |  |  |
|-----------|-------------------------------------|---------|---------|----|------------|--------------------------|--|--|
|           | Environment                         | Society | Economy | UD |            | Extreme preservationist  |  |  |
| Product   |                                     |         |         | GD |            | Resource preservationist |  |  |
| Lifecycle |                                     |         |         | ED |            | Resource conservationist |  |  |
| System    |                                     |         |         | SD |            | Resource exploitative    |  |  |
|           |                                     |         |         |    |            | Un-decided               |  |  |

## Appendix 3

|   |            |   |
|---|------------|---|
| Subject:  | Evaluator: |   |
| Methodology Shown                               |            | <p>Whether any structured method or framework for sustainability issue/problem exploration and identification was used?</p> <p>If used what method and framework was used?</p> <p>Was any method of prioritising the sustainability issues/problems used?</p> <p>Was any understanding of conflicts between different strategy was identified and reflected through approach?</p> <p>What strategy was adopted for increasing the sustainability of the product?</p> <p>How many ideas/concepts were suggested?</p> |
| What sustainability variables were pointed out? |            | <p>How sustainability was approached? Form environmental dimension, social dimension, or economic dimension.</p>  |
|   |            | Methods used  |
|   |            | Comments  |

## Appendix 4

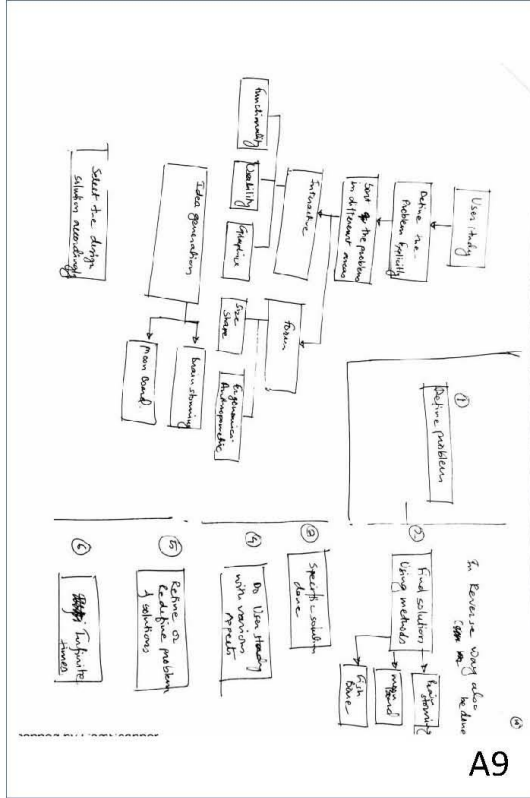
| Subject | Overall Methodology Followed |  |   |  | Type of methodology                |        |
|---------|------------------------------|--|---|--|------------------------------------|--------|
|         | Analysis                     |  | Synthesis   | Evaluation   |                                    |        |
| A9      | User study                   | Define the problem explicitly                      | Sort the problem in different areas (interactivity, usability, function, graphic; form-size, shape, ergonomic, anthropometric)              | Idea generation through brainstorming and mood board | Select design solution accordingly | Type 1 |
| A11     | Brief                        | Concept keywords (youth, form, camera, mp3 player) | Sustainability concepts keywords (lifecycle, material recycle, update of technology, less power consumption in manufacture and usage cycle) | Final concept sketches                               | Output                             | Type 2 |
| A12     | Brief                        | Problem statement                                  | Keywords-sustainability   | Initial exploration (sketches)                       | Final concept                      | Type 2 |
| A13     | Heuristics                   |  | Conceptualisation   | Final idea   | Design finalisation                | Type 3 |
|         | Existing problem             | solutions  |   |  |                                    |        |
| A14     | Market study                 | User study   | Concepts  |  | X                                  | Type 1 |

| Subject    | Overall Methodology Followed                             |   |   |  |                                |                   | Type of methodology  |        |
|------------|--|---|---|--|--------------------------------|-------------------|----------------------|--------|
|            | Analysis   |   | Synthesis                                   |  | Evaluation                     |                   |                      |        |
| <b>A15</b> | Mind mapping how sustainability is related to others     | Cause & effect diagram  | Exploring form and blending functionalities | Overall analysing & blending all the cause we formed & to get the sustainable product  | X                              |                   | Type 3               |        |
| <b>A19</b> | Product disassemble                                      | Product map<br>To use and recyclability                                       | Peripherals, charger, packaging, manual     | Paper + e electronic<br>Shipping + space   | X                              |                   | Type 3               |        |
| <b>A20</b> | Direct sketching   |   |   |  |                                |                   | Type 4               |        |
| <b>A21</b> | Identifying user   | Context of use study  | Life cycle of product                       | Disposal, recycling, reuse   | Concepts                       |                   | Final concept        | Type 2 |
| <b>A23</b> | Target group   | Target group priorities – what they want                                      | Giving weightage to each want of the user   | Lifecycle of mobile phone (cost saving, environmental impact)                          | Brainstorming                  | Prototype         | Test                 | Type 2 |
| <b>A24</b> | Sustainability is about – society, economy & environment | Approaches through multi usability so that the product can be re-used maximum | I believe in recycle, reduce and re-use     | Use eco-friendly material  | Lots can be done for packaging |                   | X                    | Type 3 |
| <b>A35</b> | Finalising need statement                                | In house research – what is sustainability, lifecycle assessment              | Reframing need statement                    | Brainstorming – sustainable materials, sustainable manufacturing, sustainable disposal | Reframing need statement       | conceptualisation | Coming up with ideas | Type 2 |
| <b>B36</b> | Directly started with concepts and ideas sketches        |   |   |  |                                |                   | Type 4               |        |

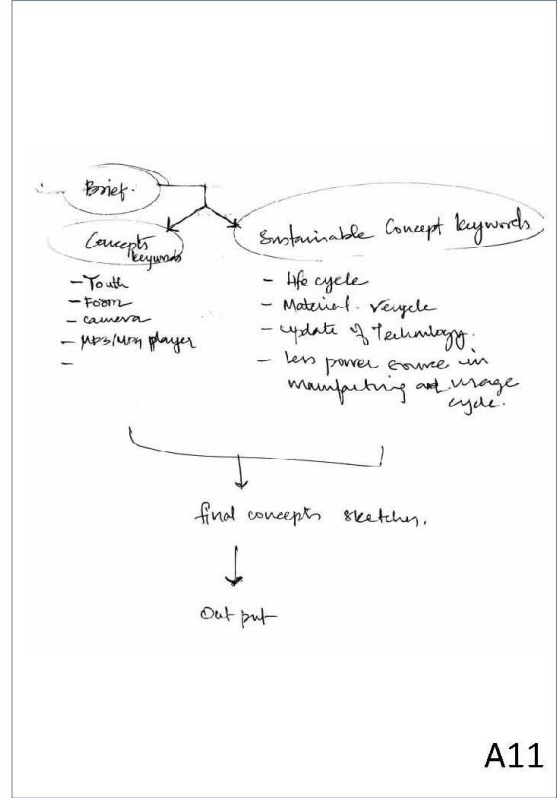
| Subject    | Overall Methodology Followed  |   |  |   |  |            |   | Type of methodology   |
|------------|---|---|--|---|--|------------|---|---|
|            | Analysis  |   |  | Synthesis   |  | Evaluation |   |   |
| <b>B45</b> | Seeing what is sustainable  | People, profit, planet (what causes pollution, what effects people, what affects planet)                      | What is mobile made of   | Different components of mobile  | Mapping different components of mobile to different aspect of sustainability |            |   | Thinking different results & innovation from mapping obtained |
| <b>B48</b> | Mapping why mobile phone is not sustainable   | What do we need to do for the issue   |  | Recycle, reuse, reduce  |  |            | X | Type 3  |
| <b>B52</b> | List design consideration with stress on sustainability factors/thoughts  | Review sustainability consideration of existing products/companies  | Distribute/divide considerations on basis of life cycle points   | Group considerations on basis of application and list desired/relevant software |  |            | X | Type 3  |
| <b>B53</b> | First we thought of the biodegradability and carbon footprint   | Then we categorise the sustainability information into different sub-categories of recycle, reuse, durability | Then we talked about the phone which is affecting the urban youth and the features affecting its feasibility in buying the product |   | X  |            | X | Type 3  |
| <b>B55</b> | Planning/designing (hardware/software), manufacturing, transportation, distribution, recycling                                  | Sustainability exploration (user, manufacture, distribution, planet)  |  | Strategy for different components   |  |            | X | Type 3  |
| <b>B58</b> | Understanding sustainability (context, purpose, durability, affordability, effect on environment (manufacture, use, after use)) | Understanding user  | User/needs (lazy, music, moody, camera)  |   | X  |            | X | Type 3  |

| Subject    | Overall Methodology Followed   |   |  |   |                                      |            | Type of methodology |
|------------|--|---|--|---|--------------------------------------|------------|---------------------|
|            | Analysis   |   |  | Synthesis   |                                      | Evaluation |                     |
| <b>B60</b> | Triple bottom-line (3BL)   |   |  | Certain ways of reducing, reusing and recycling   |                                      | X          | Type 3              |
| <b>B63</b> | Defining sustainability (in general)   | Understanding the problem statement   | Understanding the user, their needs  | Defining sustainability with respect to the user  | Jotting down variables               | X          | Type 3              |
| <b>B64</b> | Problem – time based   | Why people change to new phones   | Health issues  | User behaviour (why throw old phones, why change)   | Feature vs environment/health matrix | X          | Type 2              |
| <b>B65</b> | Choosing raw materials (durable and eco-friendly)  | Manufacturing process (less resource consumption, OS should not crash)  | Compiling (aesthetic appeal, GUI update, durable –water proof and strong, ensure resale value, low maintenance cost, overall shape - outstanding ) | Distribution packaging – recyclable, multipurpose, positive effect on user, sustainable mobile. | Maturity rate – longer lifecycle     | X          | Type 3              |
| <b>C70</b> | What sustainability means (minimise carbon footprint, affordability, ease of use, recycle, reduce, reuse, pollution) | Design variables (external hardware, connectivity, handling, durability/strength, multitasking, marketing and branding, security) | Minimising carbon foot print (reduce, recycle, durability, pollution, environmental effect (manufacture, use, disposal), technology substitution)  | Mobile (battery life, energy saving)  | X                                    | Type 3     |                     |

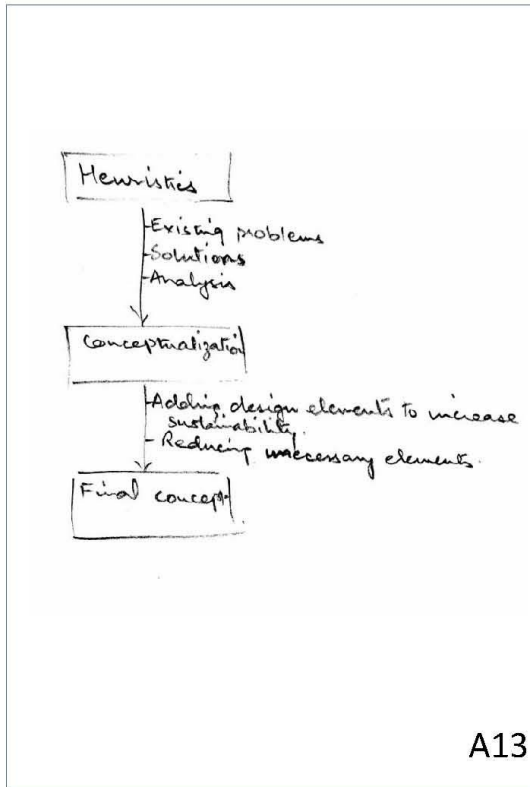
Appendix 5



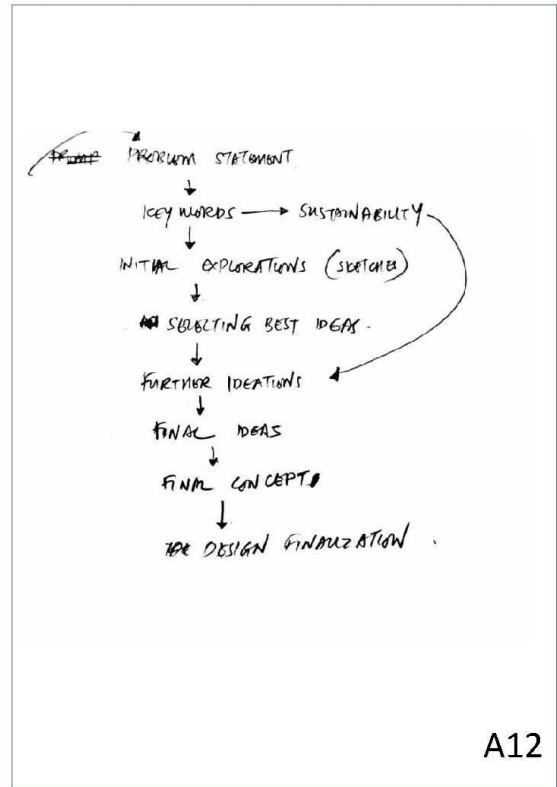
A9



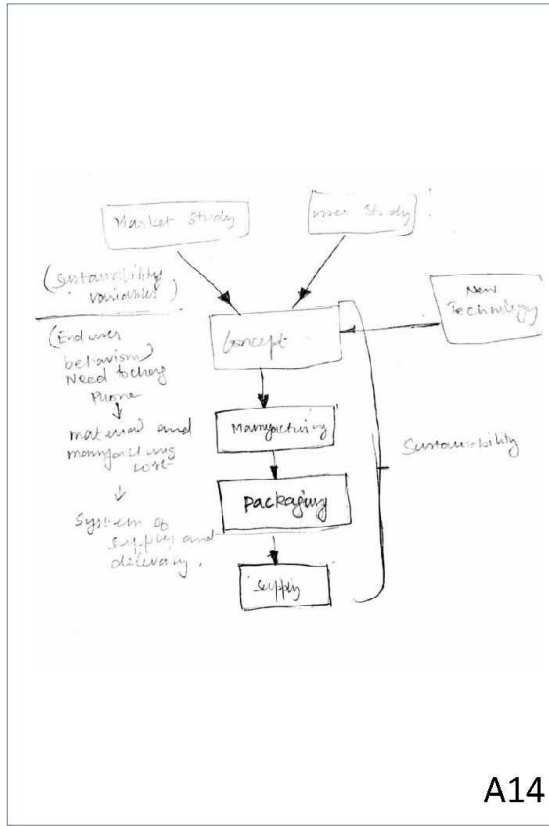
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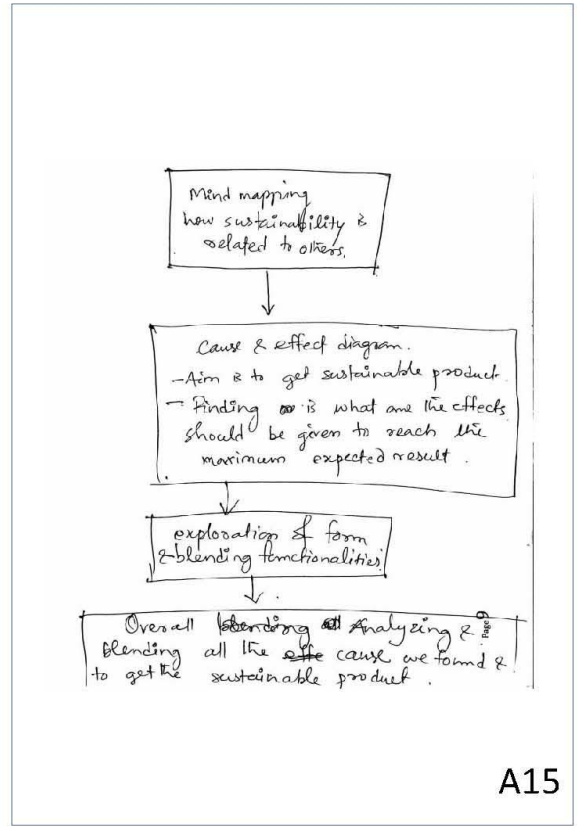
A13



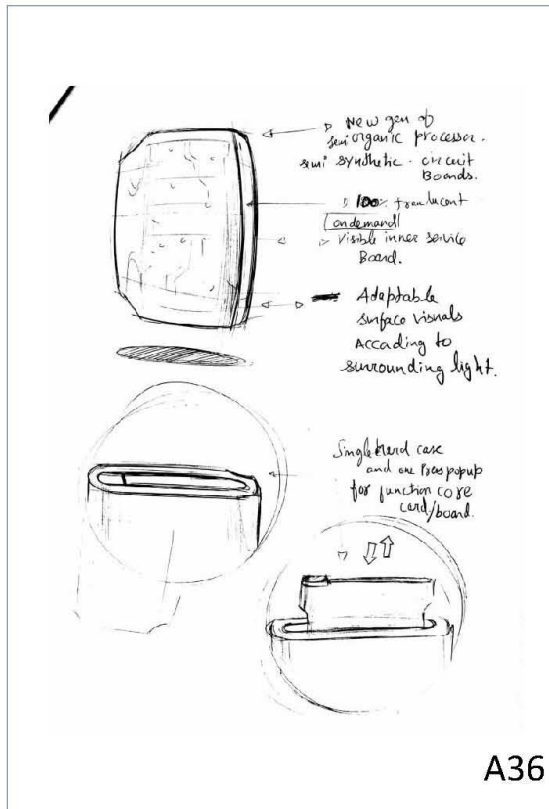
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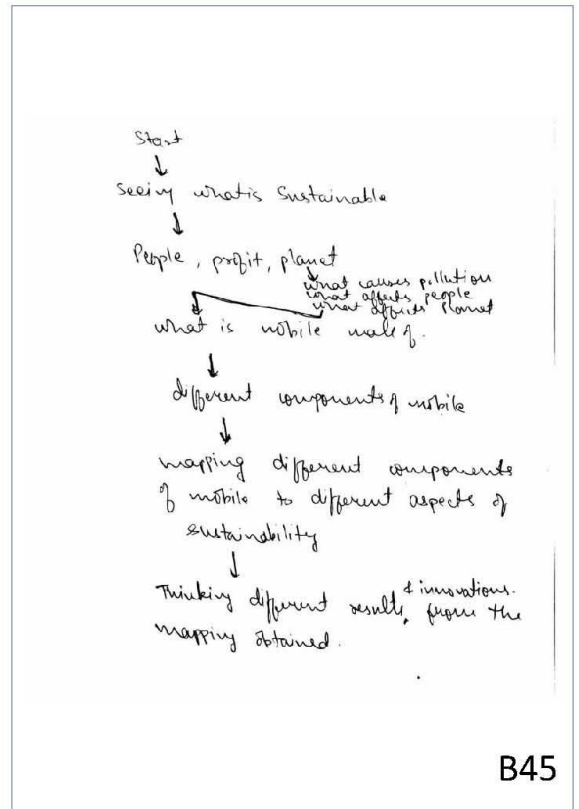
A14



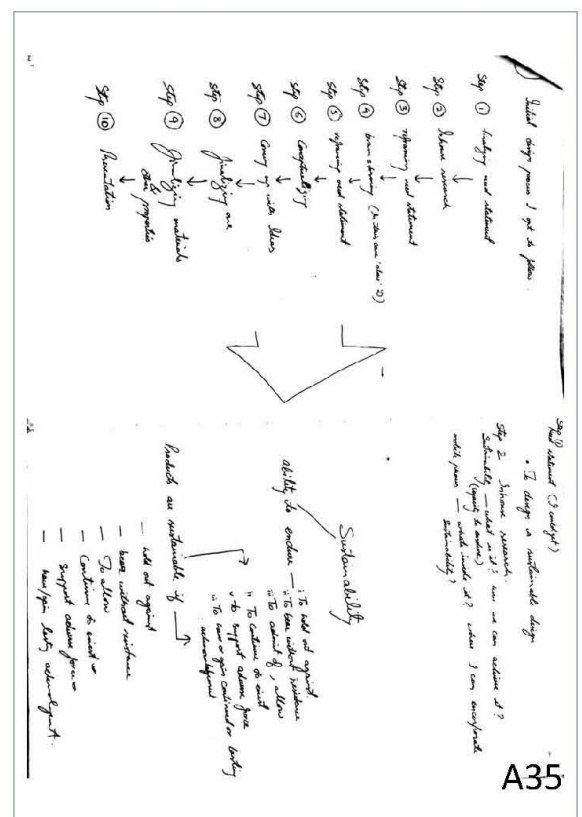
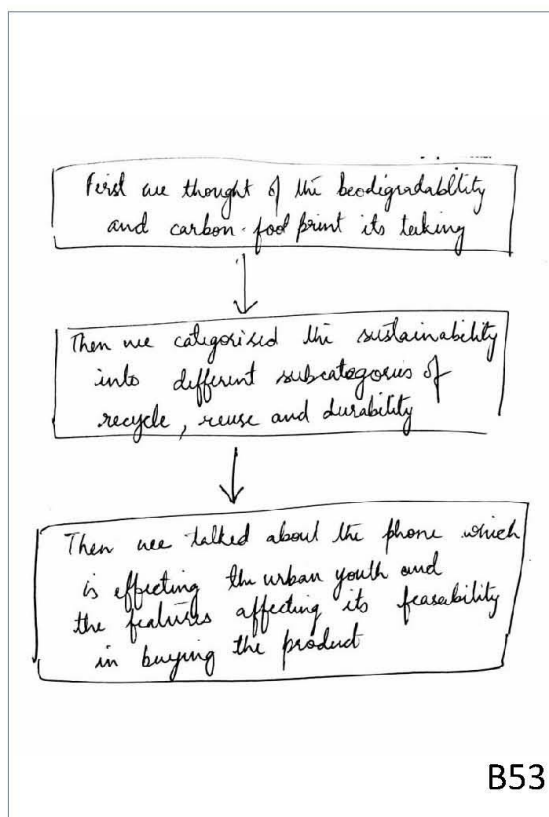
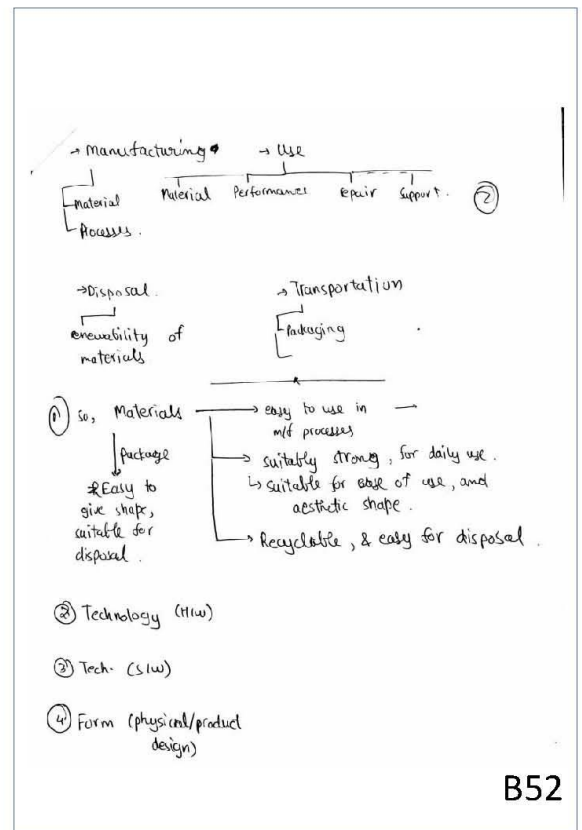
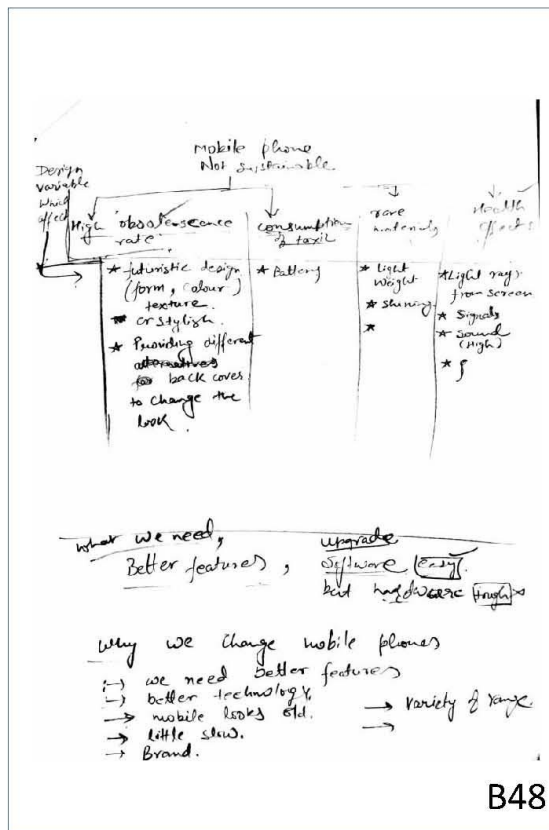
A15



A36



B45



Society, Economy, Environment → Market

Reduce → Material

Reuse → Material

Recycle → Material

May Idea

For the Indian market, Bank of Pyramid

Economy: - No Touchscreen

Functions: - Calling, Messaging, Alarms, Reminders.

Added features: - There can be an extra key ring. - There can be USB port, which can read documents, so that it can help in places like trains etc. for tickets. - Very good battery life.

A feature that directly bring help to use the mobile manually. No printed manual reqd.

**A24**

- ① Target Group.
  - ② Target Group priorities - what they want?
  - ③ Giving weightage to each 'want' of users.
  - ④ The life cycle of a Mobile phone.
    - ↳ In each stage can we save cost
    - ↳ reduce impact on environment
  - ⑤ Brainstorm / come with ideas
  - ⑥ Prototypes
  - ⑦ Test
  - ⑧ Design → do they match industry standards.
  - ⑨ Final design.
- A23**

Who is the User?

- Age Group 0-15
  - Teenagers
  - Experimental
  - show off.
  - required amount of use.
- Adults
  - less feature only calls.
  - Experimental want lot of new things
  - Not interested.
- Elderly
  - tech savvy.
  - not interested.

For what Purpose

For a middle class, working women, who also has to take care of her family.

- Wakes up in Morning
- Keeps track of time while getting ready
- Reminders.
- wears formal
- Has kids.
- Travels in Metro.
- Takes lunch from home
- Has in-laws at home.
- Salary of 30-40k
- imple stuff.

**A21**

- Step 1) Choosing Parameters
1. Feasibility: materials like aluminium or steel for the phone
  2. Eco-friendly: ~~Aluminum~~ Glass Fibre (recycled)
- Step 2) Manufacturing process.
1. Choosing manufacturing process that involve less resource consumption and judicious resource use.
  2. OS - shouldn't crash easily.
- Step 3) Compiling:
1. Giving an artistic appeal to convince user's emotional needs
  2. GUI installation: update
  3. Durability: waterproof, strength
  4. Color (aesthetic), Appeal.
  5. Ensuring Pe-SNE value of each component
  6. Low-maintenance costs.
  7. Overall shape development into a mobile that stands out from the rest.
- B65**

Reassignment Concept A22

digital watches have very low volume & they are very small and can be incorporated with any display TFT/LCD

SMALL SWITCH LED WATCH CIRCUIT

Note - this can be applied to phones which are outdated or there is a ~~space~~ problem in the circuits

- ~~Switching the~~ Switching the LED Watch Circuit ON will make the display work for the LED-watch circuit and disconnects it with the rest of the phone, making it a TABLE CLOCK

turning on the LED clock makes it a table clock

**A20**

Unknown Problems - which appear after buying a phone, while using it

System errors  
but not in the software  
Challenges

no time to fix in our hand

long time to fix in products

System not working properly

issue for daily use

we see new and better things in others' phones  
we feel a need for them  
we have money available to buy other new features, which also

Time based problems - problem which occurs with time

**B64**

High obsolescence rate  
sp. # for a sustainable design

V.A.R. - P.O.C. - S.M.A.R.T. - C.P.P.

- material
- electricity consumption
- people

modify the user behaviour to environment

Instead of launching every time a new mobile phone to introduce additional features can the existing mobile phones be modified to incorporate the features required.

e.g. like we insert a memory card to get additional storage space.

**B60**

step-1 Understanding sustainability

↳ context  
↳ purpose  
↳ how it is different for people

- \* Durability
- \* affordability
- \* affect on environment etc.

↳ in 3 phases

Manufacture    During use    after use

step-2 Smart Putting yourself in shoes of urban youth

↳ sustainability for them?

step-3 what things Urban youth requires / needs to be added / removed / improved in current mobile phones.

**B58**



## Appendix 6

**SHIV NADAR UNIVERSITY**  
(UNDERGRADUATE COURSE PROPOSAL)  
CORE COMMON CURRICULUM (CCC)

1. **COURSE TITLE** : Introduction to the Philosophy of Sustainable Design
2. **COURSE CODE** : CCC610
3. **COURSE CREDIT** : 3
4. **CONTACT HOURS** : (L-T-P) 2-0-0, Total 3 hours per week
5. **COURSE TYPE** : CCC
6. **PREREQUISITE/S** : None
7. **COURSE COORDINATOR(S)/INSTRUCTOR(S)**: Vikash Kumar
8. **SCHOOL/DEPARTMENT**: Art, Design and Performing Arts
9. **DISCIPLINE TO WHICH COURSE MANY BE OF INTEREST**: All undergraduate disciplines
10. **NO. OF STUDENTS** : 35-40
11. **COURSE CONTENT** :

**Preamble:** This course intends to introduce the philosophy of sustainable design and its dimensions through a series of lectures and hands on assignments. The course is expected to sensitize students towards sustainability and enable them to apply its fundamental principles in their day to day life.

**Content:** Society and technology – relationship; Introduction to the philosophy of sustainability and sustainable design – perspectives from different fields of study; significance in today’s context; why is it important for everyone, Historical evolution – environmentalism, environmental world view, environmental consciousness, sustainable development; Dimensions of sustainability – environmental, social and economic, Environmental sustainability, Social sustainability, Economic sustainability; Case studies, Conceptual models of sustainability, Application of sustainable design philosophy – hands on project from the chosen discipline, presentation of findings.

**12. RECOMMENDED BOOKS/REFERENCES**

- Victor Papanek, *Design for the Real World: Human Ecology and Social Change*, Academy Chicago Publishers; 2nd edition (15 July 1985), ISBN-13: 978-0897331531.
- Maggie Macnab, *Design by Nature*, Publisher: New Riders, 1<sup>st</sup> Edition, SBN-13: 978-0321747761
- Edwin Datchefski, ‘The Total Beauty of Sustainable Products (Design Fundamentals)’, Publisher: Rotovision (27 July 2001), ISBN-13: 978-2880465452.
- William McDonough, ‘*The Upcycle: Beyond Sustainability--Designing for Abundance*’, Publisher: North Point Press; 1st edition (April 16, 2013), ISBN-13: 978-0865477483

## Appendix 7



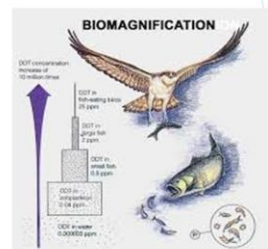
Group 1 - G1  
Task 1 - Paper

### 3. Maintaining Ecological Balance:

- Mining activities disrupt land habitats
- Water pollution disrupts aquatic ecosystems
- Heavy Metals → Paint → Pollution → Seeps into the soil → Bio magnification

### 4. Developing Environmental Awareness:

- Product does not contain guidelines for efficient disposal
- Cleaning and maintenance norms are not shared
- Provides no description of the materials used



Group 1 - G1  
Task 2 – Aluminium water bottle

### 7. Maintenance of Social Sustainability

- New range of products released with same core design, different external colour, packaging, etc. → Drives consumerism
- Heavy metals and inner coating for insulation of heat have the potential to be harmful for human health

### 8. Sustaining Economic Growth

- Profitable to companies
- Competitive market of products exists (better, more sustainable design)

Group 1 - G1  
Task 2 – Aluminium water bottle

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## List of Publication resulting out of the research work reported in this thesis

1. Pradeep Yammiyavar and **Vikash Kumar**, “E-Waste generation from mobile phones and sustainability issues for designers”, presented at International Conference on Research into Design, IISc Bangalore on January 11, 2011; published by Research Publishing, Chennai, titled “Research into Design – supporting sustainable product development” page no 523-532, ISBN:978-981-08-7721-7
2. **Vikash Kumar** and Pradeep Yammiyavar, “Systems Approach to a Sustainable Transportation System - An Overview”, presented at HERS Round table technical meet, IIT Guwahati on October 11, 2010; published by IIT Guwahati, in the proceedings of ‘National Round-table technical meet on Hybrid Renewable Energy Sources for Public Transportation Systems, page no 69-74.
3. Prakash Kumar, **Vikash Kumar** and Pradeep Yammiyavar, “GUI based remote public bus transport management system for Guwahati with a proposal for Sustainability assessment”, presented at ‘Symposium on Human Computer Interaction Design in Virtual Environments’, IIT Guwahati on March 16, 2012.
4. **Vikash Kumar** and Pradeep Yammiyavar, “Role of Ergonomics in Sustainable Product Design - A case study of ergonomic consideration in bus design for IITG campus”, abstract published in the proceedings of ‘International Conference on Humanizing Work and Work Environment- ERGO 2012:Safety for all’ page no 198.
5. **Vikash Kumar** and Pradeep Yammiyavar, “Towards development of a tool for integration of sustainable development in education – a case study of design education in India” presented at International Conference on Environment and Humanities, Eco-revolution 2013, Pokhara, Nepal on October 1, 2013; abstract published by Eco-needs foundation, India, page no 41, ISBN: 978-62951-818-3.
6. **Vikash Kumar** and Pradeep G. Yammiyavar, “What Sustainable Design Means for Novice Creative Designers: An Exploration of Their Perceptions and Mental Models in the Indian Context” presented at International conference on Design for Sustainable Well-being and Empowerment 2014, IISc Bangalore to be published as book chapter titled 'Design for Sustainable Well-being and Empowerment: Select Papers' (*under printing*)
7. **Vikash Kumar** and Pradeep G. Yammiyavar, “Indian Cultural Practices as a Manifestation of Environmental Worldview – An Exploration as a Tool for Environmental Stress Mitigation” National Seminar on Environmental Stress and Remedies 2014, Gwalior MP.