

The current status of environmental sustainability implementation during the design process in New Product Development

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Abstract:

Environmental sustainability during New Product Development has been identified within literature as being a key issue. The design process has been highlighted as having a great impact on the overall sustainability of a product and has been a rising theme for academic and industrial interest. Although there is an extensive range of literature identifying key methodologies, tools and factors of environmental sustainability to be implemented during the product design process, it is unclear of what is currently being implemented by product designers within industry. This study explores the themes of environmental sustainability and the design process through a literature review and semi-structured interviews to understand the current status of environmental sustainability during the product design process. From this study an initial conceptual framework has been developed to illustrate this. Future research directions have also been outlined.

Keywords: Product Design; Environmental Sustainability; Sustainability; Design Process; New Product Development

1. Introduction

Sustainability is a wide-ranging issue and the importance of implementing sustainability during the product design process during New Product Development (NPD) is increasingly being recognised by both academia and industry. Sustainability is most commonly defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland et al., 1987, p. 16). Three pillars divide sustainability into social, environmental and economic needs (Clark et al., 2009), this study focuses on environmental sustainability. Product design is an industry which provides creative solutions to aid sustainability and is estimated to have up to 80% impact of the overall sustainability of a product during NPD (Ahmad et al., 2018; Waage, 2007; Yang and Song, 2006).

Previous literature has focused on Design for Sustainability (DfS) methodologies and identifying factors of sustainability highlighted to improve the overall sustainability during NPD. However, it remains unclear how industry currently integrates environmental sustainability into the design

process. To address these gaps this study describes the results from 12 semi-structured interviews with product designers investigating the current status of environmental sustainability integration during NPD. This review has enabled the development of an initial conceptual framework illustrating the current status of environmental sustainability as well as offering suggestions for future research.

2. Theoretical Background

2.1 Environmental Sustainability

DfS are a range of methodologies to aid the integration of sustainability during the product design process; green design, eco-design, emotional durability, and cradle-to-cradle are all examples of DfS methodologies (Ceschin and Gaziulusoy, 2016). However, DfS methodologies present conflicting information about what should be considered to enable sustainable design. For example, cradle-to-cradle encourages designers to use waste as food or input for new design processes (Bjørn and Strandesen, 2011) whereas emotional durable design focuses on the longevity of a product (Haines-Gadd et al., 2018). Additionally, Bakker et al. (2010) discussed designers are not in the position to enforce cradle-to-cradle, and they must find a company which already implements this. Brones et al. (2014) found that although some eco-design principles were being integrated in industry, the term eco-design was rarely employed. Due to the disconnect identified within DfS methodologies and limited evidence that they are currently being actively integrated within industry, researchers focused on uncovering all individual factors of environmental sustainability suggested for implementation during the product design process.

Deutz et al. (2013) investigated eco-design within the UK through interviews, however questions focused on sustainability legislation understanding and whether designers considered general sustainable impact, waste, end of life, materials, pollution, energy, transport, or any additional concerns. There were varied responses to each factor, however researchers did not investigate all identified factors of environmental sustainability. Sustainable production principles have also previously been investigated, interviews with participants focused on the 9 Lowell Centre for Sustainable Production (LCSP) principles (Alayón et al., 2017). Although the results of this study identified some of the factors of environmental sustainability, it investigated these themes from the perspective of environmental managers or production managers opposed to designers. As designers have been identified to have up to 80% impact on the overall sustainability of the product (Ahmad et al., 2018; Waage, 2007; Yang and Song, 2006) it is important to target and understand this demographic specifically. The identification of the 18 factors as well as the investigation into previous studies have enabled the framing of key questions to explore these themes during the interviews.

2.3 The typical product design process

The product design process is described in several ways throughout literature. First, Deutz et al. (2013) categorise the structured design process as design brief, functional requirement, conceptual design, embodiment design, detailed design and consultation. The design process can also be divided into four stages (product planning, conceptual, embodiment and detailed design) (Buchert et al., 2017). The typical design process, as depicted in Figure 1, generally consists of six stages, the

preparation stage, concept design, embodiment design, detail design, design finalization and process planning and production (Wright, 1998; Chiu and Chu, 2012). The typical design process was important within the study to help frame questions on the management and integration of the identified 18 factors of environmental sustainability as well as in the development of the initial conceptual framework.

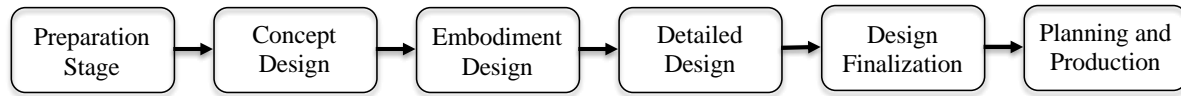


Figure 1. Typical Product Design Process adapted from (Wright, 1998; Chiu and Chu, 2012).

3. Methodology

3.1 Literature Review

First, a thorough literature review was conducted to provide theoretical background to the study which identified key factors of environmental sustainability, see Table 1. No previous study has investigated all 18 factors from the perspective of the designer in industry, this aided the development of interview questions. Academic Libraries powered by EBSCO, Scopus and Google Scholar were used to conduct the search of literature spanning themes of product design, DfS and environmental sustainability over a 40-year period. This time was selected due to the release of the Brundtland Report (1987). Over 200 papers were initially screened through reading the title of the paper. Following this a more detailed screening was conducted, consisting of reading the abstract and table of contents, this removed around 100 irrelevant studies and papers in other languages. Finally, the papers were read in full to ensure a detailed review and only the most relevant literature was selected for this study, resulting in 41 papers.

Table 1. Factors of Environmental Sustainability

Factors of Environmental Sustainability	Brief Definition	Supporting References
6Rs	Reduce, reuse, recycle, recover redesign, and remanufacture.	(Metta and Badurdeen, 2013; Yan and Feng, 2014; Go et al., 2015)
Global Warming and Emissions	Greenhouse, ozone depletion, acidification, and oxidation potential.	(Gardner and Roseland, 1989; Rosemarin, 1989; Glavič and Lukman, 2007)
Waste	Waste should be minimised, including process, packaging, assembly, disassembly and defect.	(de Ron, 1998; Stuart et al., 1999)
Energy	Energy use and energy efficiency.	(de Ron, 1998; Graedel and Guth, 1990; Tang and Bhamra, 2008)
Renewable Energy and Resources	Resources which are in a continuously renewing state.	(Glavič and Lukman, 2007; Singh et al., 2007)

Material and Resource Utilization	Minimize the consumption of resources without reducing the benefits of the product.	(Ceschin and Gaziulusoy, 2016; Metta and Badurdeen, 2013)
Material Selection	Selecting materials.	(Graedel et al., 1995; Eddy et al., 2015)
Process Selection	Selecting a manufacturing process.	(Stuart et al., 1999; He et al., 2019; Zhang et al., 2020)
Transport and Logistics	Determining transportation methods during the product lifecycle.	(de Ron, 1998; Venkata Rao, 2009; Singh et al., 2007)
Durability and/or Longevity	Extending product lifetime whilst remaining the same form and functionality.	(Zhang et al., 2020; de Ron, 1998; Vimal et al., 2016; Yan and Feng, 2014)
Modularity	The degree to which a product's components may be separated and recombined.	(Hata et al., 2001; Sonego et al., 2018)
Eco-Business	To consider the economic advantage of sustainability.	(Pieroni et al., 2019)
Structural and Functional Considerations	The adaptation of structural or functional properties to improve sustainability.	(Graedel et al., 1995; Kuo and Wang, 2019; Eddy et al., 2013)
Resource Depletion	The consumption of resources per unit production.	(Metta and Badurdeen, 2013; Go et al., 2015; Hapuwatte and Jawahir, 2019)
User Behaviour	To understand how consumer behaviour creates a demand for sustainable products and how their behaviour impacts sustainability.	(Venkata Rao, 2005; Chen, 2001; Tang and Bhamra, 2008)
Toxicity and Hazardous Production	The by-products of production which can cause harm.	(Chen, 2001; Overby, 1991; Rosemarin, 1989)
Government Regulations/Laws/Guidelines	Laws which have been introduced by the government to encourage sustainability.	(Wang et al., 2020; de Ron, 1998)
Packaging	Considering sustainability factors during packaging design.	(Chan et al., 2014; Graedel et al., 1995)

3.2 Semi-Structured Interviews

Following the literature review, in-depth semi-structured interviews were conducted with 12 industry professionals. Questions concentrated on the 18 factors of environmental sustainability, determining whether the participant considered each factor, when during the design process they considered them, whether they employed any DfS methodologies, if they used any tools and

whether there were any stakeholders involved in the design process. Each interview lasted between 40 and 70 minutes, this enabled the participant to answer all questions as well as for the researchers to explore and clarify these answers for further information. All interviews were recorded and transcribed. This enabled coding of key and common themes, using NVivo software.

To explore these themes successfully, participants were purposefully selected using two main selection criteria: (1) the participant must have experience working within the product design industry and (2) the participant must have experience in environmental sustainability. Researchers used two reach-out methods to identify potential candidates for the study. The first method was to reach-out to businesses with a strong sustainability background, this included investigating their current products for sustainability features as well as looking at their company ethos for sustainability values, to ask members of design teams to participate. The second method was completed via contacting designers directly via LinkedIn, prior to reaching out researchers viewed their public profile for evidence of product design and environmental sustainability experience. These methods resulted in 12 participants, with varying levels of experience. See Table 2 for a summary of participants.

Table 2. Participant Profiles

Participant ID	Occupation	Experience
ID-1	Product Designer	3 Years in Industry, Completed a master's degree in Sustainability.
ID-2	Product Designer and Sustainability Consultant	9 Years in Industry, Founder of a sustainable product-based company.
ID-3	Designer of Sustainability in the Built Environment	8 Years in Industry, Lecturer for 9 Years, Researcher for 7 Years.
ID-4	Product Designer and Developer	2 Years in industry, 1 year for a sustainability product-based company.
ID-5	Sustainable Designer	10 Years in Industry, Completed a master's degree in Creative Sustainability.
ID-6	Sustainable Designer	1 Year in Industry, Completed a bachelor's degree in Sustainable Product Design.
ID-7	Sustainable Designer	4 Years in Industry, 1 Year as a researcher focused on bio-based fabrics.
ID-8	Sustainable Designer	7 Years in Industry, 3 Years employed as a Sustainable Designer, Completed Business Sustainability Management Course.

ID-9	Sustainable Designer and Researcher	11 Years in Industry, 5 Years employed as a Sustainable Designer, Completed a master's degree in Eco-design and Eco-innovation.
ID-10	Product Developer and Sustainability Consultant	14 Years in Industry, 2 Years employed as a Sustainability Consultant, Completed Business Sustainability Management Course.
ID-11	Product Designer and Developer	8 Years in Industry.
ID-12	Designer	15 Years in Industry, Studio Lead at a school of design, Completed a Sustainability Education Course, Member of a collective called the Climate Designers.

4. Results

User behaviour, energy, material and resource utilization and structural and functional considerations were all factors which were considered but predominately as general design criteria with some sustainable benefits. Packaging was identified to be a separate process by the majority of participants.

Government guidelines, eco-business toxicity and process selection were mostly identified to be out of the designer's control. ID-6 stated that "process selection is harder to control" and that a "level of trust" is required between the designer and manufacture to ensure that they are being responsible, this was supported by ID-8. Business managers and CEOs were also identified as having the control and responsibility over these factors and ID-10 suggested that they should encourage their design team to design for sustainability opposed to saving cost and that a "businesses need to make a shift" to enable further sustainable development.

When discussing management and assessment methods for environmental sustainability during the product design process, many participants had "no measuring method or tool" and often just feel "confident in the methods" (ID-6) which they have employed. However, ID-8, ID-9 and ID-10 all currently or have previously employed the LCA method but ID-8 found them "long and not very accurate" and ID-9 felt that "good access to material databases" were essential for designers to be successful.

4.1 Product Design Environmental Sustainability Framework

To aid in the implementation of environmental sustainability during the design process, the data collected and analysed from the semi-structured interviews has enabled the development of an initial conceptual framework. This framework illustrates the current status of environmental sustainability integration within the product design process. The framework follows the typical product design process, shown previously in Figure 1. Throughout the interviews, participants indicated that although some of the factors discussed had environmental sustainability benefits, they did not view them as primarily environmental sustainability factors. Factors were primarily categorised by participants as environmental sustainability factors; however some were categorised as design criteria with environmental sustainability, stakeholder responsibility opposed to designer responsibility and others were part of a separate process from the design process. Table 3 indicates these 4 categories.

Table 3. Categorisation of the 18 environmental sustainability factors

Environmental Sustainability	Design Criteria	Stakeholder Responsibility	Separate Process
<ul style="list-style-type: none"> - Material selection - 6Rs - Renewable material and resources - Resource depletion - Transport and Logistics - Durability - Modularity - Global Warming and Emissions - Waste 	<ul style="list-style-type: none"> - User behaviour - Energy - Material and resource utilization - Structural and functional considerations 	<ul style="list-style-type: none"> - Government regulations/ laws/ guidelines - Toxicity and hazardous production - Process selection - Eco-business 	<ul style="list-style-type: none"> - Packaging

The framework, shown in Figure 2, integrates the environmental sustainability and design criteria into the typical product design process as well as any tools or stakeholders. The placement of each factor aligns with the information received through the semi-structured interviews.

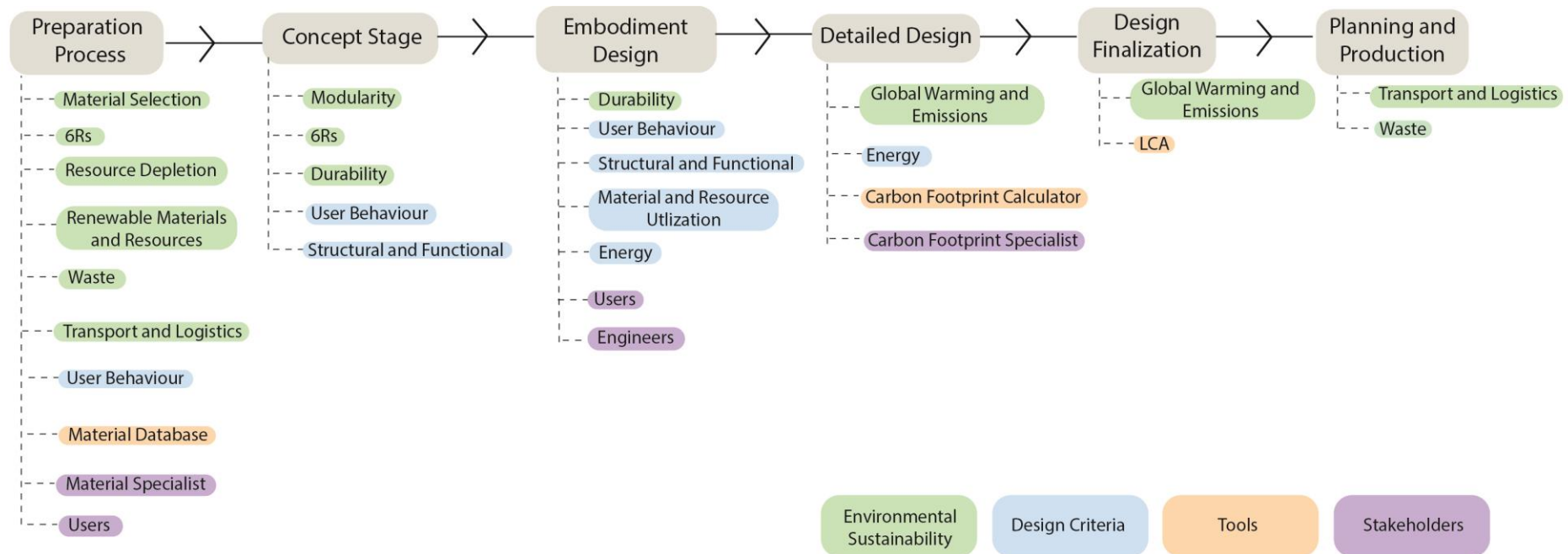


Figure 2. Initial Conceptual Environmental Sustainability Framework

5. Discussions

From the two-stage methodology it is apparent that environmental sustainability is an extensive and complex topic within product design. The identification of 18 factors reinforces product designer's responsibility during NPD. The semi-structured interviews provided insight into the current status of environmental sustainability in the product design process, as well as the general understanding of environmental sustainability of practicing designers. Out of the 18 factors, participants were confident in the factors that focused on their design principles such as material selection and user behaviour opposed to factors like government regulations. This identified some areas of limited knowledge from designers, it is also unclear whether companies are equipped to handle government regulations in relation to environmentally sustainable product design. There are potential implications for this gap in expertise, as the product design stage has been identified as having up to 80% impact of the sustainability of a product (Ahmad et al., 2018; Waage, 2007; Yang and Song, 2006), it is therefore important that product designers are effectively educated in environmental sustainability and how to integrate this into their design process. Businesses and governments also have a responsibility to equip and inform design teams on changes on regulations that their products must adhere to so that they can be integrated into the product design stage. Additionally, participants didn't necessarily agree with literature's conclusion that all factors were (a) environmental sustainability focused and (b) their responsibility. Further investigation is required to determine what is the designer's responsibility and how to ensure all stakeholders of the NPD process enable successful implementation of environmental sustainability. Furthermore, this study specifically targeted designers with environmental sustainability experience. This could suggest that other product designers without this expertise are less knowledgeable or experienced in implementing environmental sustainability and may need further support in this area.

To address the research question of this study, an initial conceptual framework was developed to illustrate the current status on environmental sustainability in the product design process during NPD. Further investigation is needed to develop this framework on variables such as stakeholder integration, management, assessment and whether the framework needs to be adaptable to suit various product types. As the majority of participants did not have a method of assessing or managing environmentally sustainable NPD, it is suggested that future research aims to address this.

5.1 Suggestions for Future Research

Three themes were identified for future research: design education, government responsibility and circular economy. It was clear from the semi-structured interviews that participants that had taken sustainability-specific courses were more confident and knowledgeable when answering the questions, but they also identified that this shouldn't have to be an additional course and should be integrated into the foundations of design education. Research is required to investigate the current status of design education and how it is equipping future designers with the skills of sustainability. Government regulations was a factor predominately identified by participants as not their responsibility, but participants also discussed that they felt legislations should be stricter to ensure sustainable NPD, further clarity and development is required for sustainability-focused laws. Finally, many participants discussed circular economy during their interviews, as a methodology which they consider aiding environmental sustainability during the design process. This has identified a key concept which should be investigated further to aid sustainable NPD.

6. Conclusions

Literature and industry both acknowledge that environmental sustainability is a key issue and are actively trying to develop solutions to aid it during the product design process. Data collection and analysis has enabled a review of the current status of environmental sustainability integration during the product design process. An initial conceptual framework has been developed to illustrate the placement of environmental sustainability factors during the product design process concluded from the findings of the data analysis. The study has also suggested areas of improvement to further develop environmental sustainability during the design process.

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