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Taxonomy of design strategies for a circular design tool

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Abstract
This paper presents the development of a circular design tool created from a taxonomy of design strategies related to circular economy aspects that emerged from an extensive literature review. The taxonomy was presented to 10 experts on circular economy and design through a survey to identify an importance factor that could guide product designers to rate different concepts. The taxonomy and their rates are presented in a circular design tool to help product designers to avoid uncertainty of which design concepts meets circular economy aspects. A pair of trainers are used as an example on how the circular design tool can be used. The paper discusses how the chosen design meets the identified circular design aspects and acknowledges that more trials with different product categories are needed to determine further areas of improvement. A larger survey is also suggested to develop a more accurate scoring system when it comes to rate each concept. The paper concludes that more detail guidelines are needed for product designers in their early career, so they can consider design for circular economy. In addition, the final remarks elucidate that future research is needed to cross-reference the circular design aspects with technical aspects of each product, new manufacturing technologies and materials.

Introduction

The circular economy ideology replaces the end-of-life concept with restoration, using renewable energy, eliminating the use of toxic chemicals that impair reuse, and aims for the elimination of waste through the superior design of materials, products and systems. As such, design for a circular economy must consider design strategies for closed-loop systems within a technical cycle (synthetic materials stay in continue use without losing their properties and value) and a biological cycle (organic material returns to the natural system providing nutrients that don't cause harm) (McDonough and Braungart, 2002).

In early 2017, design consultancy IDEO with The Ellen MacArthur Foundation released the 'Circular Design Guide' (IDEO, 2017) that complies 24 different methods classified in four different stages: Understand, Define, Make and Release. The guide combines Circular Economy and Design Thinking principles to inspire designers to create solutions for the Circular Economy. The guide is built for design tangible (e.g. durable products) and intangible (e.g. services) solutions.

Despite the 'Circular Design Guide' presents a handful of methods and templates to inspire designers, it misses to help product designers to avoid uncertainty of which concept meets circular economy aspects. In addition, the guide also misses to include valuable literature on Design for Sustainability, considered as the predecessor of Circular Design (Moreno et al. 2016).

The aim of this article is to identify a taxonomy of design strategies that could be useful to guide product designers on how to conceptualise durable and single use products for a circular economy by foreseeing possible solutions for close-loop systems. To meet this aim, the paper presents the development and a first implementation of a circular design tool for an European context.

Methods and scope

To build the proposed circular design tool, first the authors conducted a literature review to complement the taxonomy of DfX approaches translated into circular design strategies presented by Moreno et al. (2016). The latter work presents an inclusive taxonomy with all the DfX strategies suitable for circular design, resulting in the most comprehensive one to build upon this current work. This is because most of the academic and grey literature on circular economy has focused primarily on the development of business model structures (e.g. Lewandowski, 2016; Lacy and Rutqvist, 2015; Bocken et al., 2013,2015; Stahel 2013 and Tukker, 2015) with a small number of studies addressing design strategies and principles (Bakker et al., 2014a, 2014b; Bocken et al., 2016; den Hollander et al., 2017) that cover all spectrums of the circular economy (i.e. technical and biological cycles).

The literature review focused on discovering other product design aspects that could be useful to implement a circular design. Business model and policy aspects that surround the product development were dismissed in this stage, as these were covered in the latter study. In addition, the focus on 'design' helped to untapped other design thinking aspects that can be integrated to change the role of design within the circular economy, such as technological developments and user experience.

Scopus and Google Scholar were used in the initial literature search using concepts like: 'circular design', 'circular economy', 'sustainable design', 'product design', 'design thinking', 'eco-design', 'sustainable design', and 'design for sustainability' with the combination of words such as: 'definition', 'guidelines', 'strategies', 'indicators', and 'standards.' The review of the literature is presented in full in 'A guide for circular design' (accessible via Kings Norton Library Master Thesis Archive), which describes in detailed how the revised taxonomy was built upon relating the identified design strategies to circular economy aspects.

This revised taxonomy was presented to 10 experts on circular economy and design through a survey. Respondents were asked to grade each identified design strategy and activity per the circular design aspects that they were related to. The answers of the survey helped to establish an importance factor between 0 and 5 that served as a guide to score a concept selection when designing a circular product. The taxonomy was then depicted in a tool that used a ludic approach to provide information by using visual elements to captivate its use along designers.

The tool was then used to conceptualise a pair of trainers, following a traditional design process. A pair of trainers was chosen, as an example of a durable product which follows a complex design within the take-make-dispose linear economy.

Taxonomy and survey results

The revised taxonomy (Table 1) takes a holistic approach to product development considering material selection, manufacture processes, distribution, use and end-of-life. It compiles and classifies different activities to consider in the conceptualisation phase of the design process, according to the identified design strategy and circular design aspects.

Through an online survey, experts in circular economy and design were asked to score between 0 and 5 each of the identified strategies and activities to define the impact (or importance) factor that each specific design strategy and activity have when developing a new product. An average score from the survey was calculated to stablish a circularity factor in which each activity is rated as seen in Table 1.

Circular design tool

From the presented taxonomy, a circular design tool (figure 1) was created to present the information in a non-scientific language with the aim to be easy to use, to educate and inspire during the concept development phase.

The tool helps to rate each concept according to the circularity factor. However, since the circularity factor came from experts' opinion, this cannot be considered as an ultimate score. As such, the tool is designed to consider a subjective score from the designer, considering the specific product and context around it. An explanation of how to use the tool to score each concept can be seen in Figure 2.

Figure 1. Circular design tool.

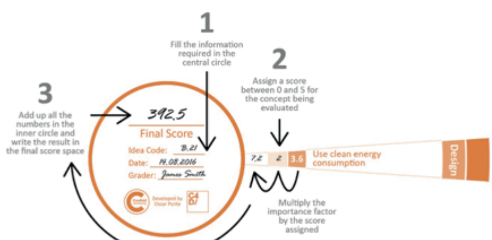

Figure 2. Circular design tool scoring instructions.

Designing a pair of trainers using the circular design tool

The tool was used to design a pair of 3D printed trainers by choosing different design strategies and scoring different concepts (Figure 3).

The selected design consists of a two-part trainer (Figure 4). A Selective Laser Sintering (SLS) technology was selected with a Thermoplastic Polyurethane Elastomer (e.g. Duraform Flex) as the base material to produce the trainers. This material is fully recyclable and can be used again in a SLS printer. Its properties are ideal for the footwear industry as it is flexible, durable, tear-resistant, soft-touch and washable. The design of this pair of trainers allows new disruptive business model such as offering trainers as a service through a subscription model. This model provides a personalised service if the trainers need to be repaired, maintained or parts need to be replaced, as

Circular Design Aspect	DfX Approach	Strategy	Factor
Resource Conservation	Design for energy conservation	Use clean energy consumption	3.6
		Reduce energy consumption in manufacture (eliminate yield losses)	3.3
		Improve manufacture (production steps, supply chain)	3.5
		Use processes suitable for low scale production	2.5
	Design for material conservation and eliminate waste	Select the best materials (non-toxic, pure if possible)	3.8
		Choose local materials (no-rare to avoid scarcity)	3.0
		Consider a healthy material flow	3.7
		Eliminate unnecessary parts and sub-assemblies	2.6
		Reduce material (light weighting)	2.8
		Reduce or eliminate packaging	3.2
		Reduce the size of components (miniaturise)	2.6
		Avoid composites and coating (difficult to separate materials)	4.3
		Avoid toxic adhesives, use easy-mechanic joints (fasteners, visible joints)	3.4
		Use pure materials to allow biodegradability	3.2
Life Cycles (end-of-life)	Design for optimising/extend product life	Assure reliability (quality)	3.8
		Allow reusability	4.3
		Encourage maintenance (repair/refurbish)	4.4
		Ease assembly/disassembly	4.3
		Standardise parts for compatibility (modularity)	4.1
		Remanufacture	4.0
	Design for multiple life cycles	Recover material (easy to clean, collect and transport)	4.1
		Allow cascade use	3.8
		Motivate the user to recycle	2.9
		Assure spare parts availability	4.0
Whole System Design	Design for sustainability	Shift the ownership of products into a service (swap, rent, share)	4.2
		De-materialise products into digital platforms	3.4
		Allow upgradability and flexibility to adapt	3.9
		Strengthen local industry	3.3
		Create regenerative systems (biomimicry)	3.3
		Care about social impact	3.5
		Create wealth through a good business practice (improve cost-benefit relationship)	3.6
		Develop a trace-and-return system	3.8
Customer	Design for users	Customise to wants and needs of each person	2.8
		Enhance durability (avoid built-in obsolescence)	3.9
		Develop attachment/loyalty (experience, meaningful design)	3.3
		Reduce waiting times in delivery to consumer	2.3
		Based on long-lasting trends, no ephemeral fashion (timeless aesthetics)	2.7
		Implement poka-yoke principles to ease use	2.6
Development	Design for the present towards the future	Use mobile technologies	3.1
		Use Machine-to-Machine communications (M2M)	3.2
		Use cloud computing	3.2
		Use social media technology	2.6
		Use big data analysis	3.3
		Use new material (intelligent, organic)	3.2
		Use 3D printing (avoid subtracting technologies)	3.0
		Create multi-functional teams to consider different aspects in the design	4.1

the main body detaches from the sole with a mechanical joint. In addition, trainers will be produced in local stores. The concept also includes the use of other technologies such as the ability to scan your foot to produce every trainer to measure and an augmented reality application to virtually try the trainers on. These technologies will allow the custom production of trainers avoiding a surplus of unsold products and utilizing the minimal amount of material.

Figure 3. Concept development and scores using the circular design tool.

Figure 4. Pair of 3D printed trainers using the circular design tool.

Assessing the circular design aspect of the selected design

This section discusses how the trainer meets the identified circular deign aspects.

Resource conservation: The trainer is suitable for being built in a low scale production in a single location, improving the manufacturing process by reducing the steps needed to create a final product (Allwood et al., 2011). In this case, only the process of printing is used, removing other processes like cutting, sewing, gluing and heat forming. Using 3D printing as a main process of manufacture means that there is no waste in the manufacturing process.

Life cycles – end of life: The trainer is designed to be maintained. The design allows users to change the damaged parts without disposing the entire product, as it has a mechanical joint between the sole and the upper body that helps to easy disassemble to final product (Bogue, 2007; Plant et al., 2010). Being able to recover parts of the trainer, allows to cascade the material back into the manufacturing process (Accorsi et al., 2015). In addition, the selected design and manufacturing process allows assuring spare parts, as they are printed by request.

Whole System Design: The chosen design allows certain flexibility in colours and styles, having an adaptable design (Bakker et al., 2014a). Biomimicry was included by considering a restorative process when either the sole or the upper body gets damaged by using 3D printing for repair (Andrew, 2015). The design also allows to include a servitisation model if needed.

Design for users: 3D printing allows to personalise a design with different shapes and styles, reducing waiting times in delivery to the user (Berman, 2012). The design also intends to create an attachment between the product and the user, through updating or upgrading the trainer when needed to keep on track with any fashion trend. This might help avoid built-in obsolescence (Bocken and Short, 2016).

Design for the present towards the future: Using augmented reality and 3D printing technologies can help to avoid surplus of manufactured products and unwanted items returned to the manufacture or store. The analysis of big data (out of scope on this paper) could help to assess product integrity (Ijomah et al., 2007).

Discussion

From this trial of using the circular design tool, it can be said that future versions of the tool should consider a more accurate scoring system of each concept developed, including different factors for different product categories. The current scoring system is based on qualitative data, which was translated into quantitative information based on the survey results. However, the obtained factors were based on a small sample of answers, which might vary if a larger sample is considered. In addition, the tool was conceived considering only aspects related to the circularity of the product, leaving out of scope the aesthetics and the business model around the product. Whilst there isn't an 'ideal' business model that is preferable to achieve true circularity when designing a product, it is acknowledged that future versions of the tool should include a cross match between the design and the business model, as choosing the most fitting circular design strategy is highly dependent on the specific product context in which the product will function, as acknowledge by one expert when answering the survey. In addition, the tool should be adapted to customise importance factors for different product categories, companies or contexts as pointed out by another expert. These considerations will help to tailor better a circular design approach to a chosen business model for the successful transition into a circular economy.

As a first attempt to test and use the circular design tool, the result of the designed trainer shows a good example of circularity from conceptualising a product to a final prototype. A third expert in footwear design mentioned: "the result seemed appropriate as it reduce parts and eliminates components, such as the laces. It has good aesthetics that could help to create attachment with the user, and it considers important characteristics of trainers' design such as ventilation and shock absorption." Despite this concept shows a good first attempt of using the circular design tool to conceptualise a product, still more research has to be done to cross-reference circular design aspects with technical aspects of each product, new manufacturing technologies and materials to make a fully commercial product. I.e. 3d printing technologies are in early stages of development to be used for the footwear industry, and thus further tests and adaptations to the presented design might be required for full commercialisation.

Conclusion

Designers define to a great extent, the impact a product will have through its lifetime, and thus the aim of this paper was to identify a taxonomy of design strategies that could be useful to guide product designers on how to conceptualise a product with circular economy in mind, especially in their earlier career. As discussed, the paper presents a good example on how this tool could be used to conceptualise a product, acknowledging that there is not only one answer when designing for a circular economy. In addition, a more accurate scoring system would be needed, to account for suitable importance factors for each strategy presented. Therefore, future research would see the implementation of a larger survey to have a more accurate scoring system, as well as further trials with different product categories considering the business model.

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