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Towards design strategies for circular medical products

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ABSTRACT

The framework of design for the circular economy is increasingly used in industry to improve product sustainability and decrease costs, and in academia various models have been developed to guide circular design. However, in the medical sector, although it generates a large amount of waste, application of circular design principles is difficult because of the clinical challenges of safety and sterility that reuse of products or materials entail. This paper categorizes and analyses existing instances of circular economy in the medical sector, using a literature review and examination of existing industry examples. This is used to identify challenges and unmet opportunities for circular design in the medical sector. The key factors affecting circular medical design are found to be device criticality in terms of sterilization requirements, device value and the organizational support structure around the device. A design heuristic and suggested strategies for circular design of medical products are proposed based on these findings.

1. Introduction

How can products be designed to be inherently good for the future of the planet, as well as good for the users they are made for? This is a question increasingly asked by product designers as more and more is understood about the environmental threats we face. Traditional "design for sustainability" has attempted to minimize the pollution and carbon footprint caused by products. Today, we also recognize the importance of the raw material value that is lost and the environmental damage that is imposed when products are manufactured from extracted materials, used and then disposed of in a single cycle. In response to this, the idea of the "circular economy" has developed. This is an idea which, starting from the 1970s, grew out of various schools of thought within economics, environmental science, engineering and design and has been developed further by academic researchers and industry organizations ever since (Ellen MacArthur Foundation, 2014). One of the core principles of the circular economy is that the value of products and the materials they are made of can be preserved by keeping them in the economic system, either by lengthening the life of the products formed from them, or "looping" them back in the system to be reused (Hollander et al., 2017). In the field of product design specifically, investigation into the circular economy has focused on establishing frameworks and guidelines for how products can be designed to be compatible with circular economy principles (Bocken et al., 2016). In particular, research has been performed on how to differentiate products according to which circular economy strategies would be best suited for them – for example, whether to retain a product's material value by lengthening its life or by recycling it (Bakker et al., 2014) based on its typical lifespan, function, energy consumption and perceived value by users. Though growing rapidly, research into circular product design is still in its nascent stages. As a result, little research has been done on the application of circular design principles to specific fields or industries, and how the particular needs of those industries might affect product circular design frameworks.

The purpose of this paper is to form an introduction to be used as a basis for further investigation in circular design applied to one such field: the healthcare industry. This field was chosen for investigation for two reasons: firstly because of the problems of material waste that exist within it, and secondly because of the potential difficulty of introducing circular design strategies to it. Worldwide, the amount of waste created per hospital patient per day ranges from 0.44 kg in Mauritius to 8.4 kg in the US, with EU countries tending to be between those two extremes (UK 3.3 kg, Germany 3.6 kg and France 3.3 kg) (Minoglou et al., 2017). In the US, an additional 50,000 tonnes per year is estimated to be generated from home healthcare (Kaiser et al., 2001). There are several reasons to be concerned about this. The first is that the global healthcare sector is growing rapidly due to emerging markets and ageing populations (Deloitte, 2016). The second is that general medical waste – the kind disposed of from hospitals and clinics– can present a huge health risk through re-infection. The UN estimated that over half the world's population is at risk from illness caused by healthcare waste (Georgescu, 2011).

Introducing circular economy principles into design for healthcare is challenging. Product designers in this field must already comply with

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existing regulations on product safety. Design of medical products is a high-risk field, where any potential reduction in functionality or increase in risk could endanger patients' health or even lives. And whereas in consumer products 'disposability' is usually seen solely in financial and environmental terms, in the medical industry the introduction of disposable products has greatly reduced infection and thus improved health outcomes.

This paper intends to establish an introduction upon which can be based further studies, as well as practical work by designers and engineers, on incorporating circular economy design principles in the design of medical products. It does so by first defining what is currently meant in design literature by 'circularity' in product design. A literature search is performed to find out what principles of circularity are already in place in the medical sector. This approach is then used to identify the particular challenges of circular design in the medical sector and methods of differentiating different types of medical technology based on their potential for circular design. From this, a set of strategies is developed to help designers and engineers approach the design of a circular medical product.

2. Circular economy framework

There are many different definitions of what constitutes a 'circular economy'. The definition used in this paper is one arising from the field of industrial ecology, which defines a circular economy in terms of material flows (Ayres, 1994; Stahel, 1994; Stahel, 2010; Lifset and Graedel, 2002). In a linear economy, raw materials are extracted, are formed into products, then at some point reach the end of their functional lives in the economic system and are disposed of as 'waste', never to re-enter it. A circular economy aims to eliminate 'waste', by lengthening product life and/or 'looping' the product or its constituent materials back into the system to be reused. The mechanism by which products in the linear economy become 'waste' is 'obsolescence' – defined by den Hollander et al. (2017) as a loss of perceived value of the product which leads to it being discarded from the economic system. This can take the form of, for example, functional obsolescence (i.e. the product no longer performs its intended function), technological obsolescence (i.e. the product is outperformed by newer technology), economic obsolescence (i.e. the product's use is no longer profitable), regulatory obsolescence (i.e. the product is no longer legal) or aesthetic obsolescence (i.e. the product is outmoded or its aesthetic appeal is damaged). According to the principles of a circular economy, obsolescence should not lead to waste. Rather, an action of 'recovery' (Hollander et al., 2017) must be taken to remove the product/materials from their state of obsolescence, restore perceived value, and thus return them to the economic system. Different methods of recovery are defined in the literature. Repair, for instance, involves a reconfiguration or replacement of parts to restore a product from functional obsolescence caused by a specific fault. Products which are obsolete or near obsolescence (e.g. through wear-and-tear) can be retrieved by manufacturers at the end of their lifecycle and put back into service by the replacement of crucial parts, a process known as refurbishing or remanufacturing (Thierry et al., 1995). Recycling is employed when a product can no longer be recovered from obsolescence in its current form, but must be broken down into its constituent materials, which then regain value with a different function.

The methods of recovery can be ranked according to the 'inertia' principle of Walter Stahel, which states "Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system." (Stahel, 2010, p.195). In other words, value can be maximised and environmental losses minimized if a product is recovered by changing it as little as possible from its original manufactured state. In product design terms, this can be thought of as the maximization of 'product integrity'. The extent to which product integrity can be maintained depends on both the product itself and the way in which it has become obsolete. The impact of product design on recovery is often described in terms of 'repairability', 'remanufacturability' or 'recyclability' (Prendeville et al., 2015; Mulder, 2012). The type and severity of a product's obsolescence also affects the way in which it is recovered – for instance, aesthetic obsolescence may be reversed by making minor changes to a product's appearance (i.e. repair), technological obsolescence may require refurbishing or upgrade, and severe functional obsolescence might leave recycling as the only option for material recovery. The integrity of a product can also be said to have increased if it becomes obsolete less frequently. For example, making a product more robust could increase its mean-time-to-repair (the time between necessary recovery by repair) or its overall lifespan (the time until which recovery actions of lesser integrity – such as recycling or refurbishing – are required). In both cases, product integrity is maximized over time since fewer of the materials required for recovery are expended overall.

3. Method & scope

Using the above terms, a 'circular' product could be defined as a product that is able to go through repeated cycles of obsolescence and recovery while maintaining the highest level of integrity possible. Therefore, when assessing how 'circularity' can be applied in the medical industry, it is important to understand the ways in which products within it become obsolete, and what methods – if any – are already being used for their recovery from obsolescence. This can be used as a starting point for analysing the constraints of and opportunities for circular recovery of medical products. This paper is therefore structured as a literature search, based on the following questions.

Research Question 1: What examples exist of product/material recovery in the medical industry?

Research Question 2: What are the causes of product obsolescence in the medical industry?

Research Question 3: What strategies can designers use to encourage recovery?

To answer RQ 1 and 2, a literature review was performed in accordance with the procedures described in Hagen-Zanker and Mallett (2013). Since circular economy in the medical sector is not a distinct field with its own terminology, and relates to many different disciplines, a broad number of search terms was defined so as to capture as many instances as possible of 'obsolescence' and 'recovery'. An initial list of search terms was assembled consisting of combinations of the a first group of terms relating to circularity, obsolescence, and recovery and a second group of terms relating to the medical industry (Table 1). An academic literature search was performed to create an initial body of literature. Literature searches were performed using Scopus, Google Scholar and Pubmed databases.

Given the relatively academically unexplored nature of circular economy in the medical sector, non-academic 'grey literature' was also searched. This included journalistic articles, policy documents and the website and brochures of medical equipment manufacturers. Grey literature was initially searched for in Google using the same initial search terms. Using snowballing, new keywords emerged from both academic and grey literature and were subsequently added to the set. The results of the searches were scan-read for evidence of either a cause of obsolescence or an instance of recovery; as defined earlier in this paper. Irrelevant papers were discarded.

It should be noted that articles were not spread broadly over different sub-topics, but tended to exist in "clusters", with high numbers of articles concentrated in specific areas where medical circularity happens to overlap with an existing field. For instance, many articles were found from medical journals on the proliferation and clinical consequences of the reuse of single-use devices (SUDs), since this is an important topic in clinical infection control. However, far fewer articles were found on the effect of SUD design on reuse, since the issue has not