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Developing circular business models: LCA and strategic choice

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Abstract

Transitioning towards a more circular economy achieving sustainable business requires both radical change and collective efforts. Succeeding with the development of circular business models means addressing the challenge at hand from several levels including value chain, organizational, process and product. Increased competitive advantage through offering more circular business models are enticing opportunities explaining why value chains collectively address these challenges. At the product level of 'sustainability-by-design', extended product-lifetime is often a first go-to with objectives of achieving increased sustainability or reduced environmental footprint. One challenge is acknowledging and aligning all aspects constituting the product lifetime, this being *technical*, *economic*, and *actual* time in use – where the latter reflect the end user behaviors. Overcoming these challenges requires products that are designed to encourage the customer and end user to take sustainable choice when acquiring the product, during its lifetime, and performing correct disposal at end of product lifetime. This paper reports preliminary findings from an ongoing research project with a case from the Norwegian furniture industry. The objective of the research project is to reduce the case product environmental footprint by 50%. Achieving this objective requires a methodology and mind-set of radical change. As an initial baseline we have conducted a life cycle analysis (LCA) utilizing the SimaPro software identifying the product current environmental footprint. This forms the baseline for questioning specific components, their function and their choice of material and design. The research question addressed in this paper is *how to develop circular products and new business models enforcing sustainable behavior both for the manufacturer, its supply chain and the end customer/user?* The majority of the furniture supply chain are partners in the research project; hence this paper takes on a view of the design process as a collective process in an industrial context contributing to the sustainability-by-design discussion.

Keywords: Life Cycle Assesment; Circular Business Model; Circular Design; Environmental Footprint

1. Introduction and theoretical foundation

The global manufacturing industry is undergoing major changes to meet stakeholder and regulatory requirements. These changes are associated with environmental, social and governance reporting and how negative impact are reduced or avoided. Implementation of programs to improve *process effectiveness* have sustained competitive advantage [1]. With the new ESG requirements *resource efficiency* will have a pivotal role for the manufacturing industry in the years to come [2, 3]. This is also true for the Norwegian manufacturing industry which is facing strong international competition. Customers increasingly demand more sustainable products and services in the form of requesting environmental product declarations (EPD), solutions for more recycling and end-of-life solutions with low environmental impact.

1.1. *Developing circular business models as a collective effort*

Transforming linear business models and developing them into circular models has received increased attention in recent years as a powerful move towards sustainability [4]. Circular economy concerns decoupling economic growth from negative

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environmental impact [5, originally developed by 6]. Succeeding with the development of circular business models means addressing the challenge at hand from several levels [7] including value chain, organizational, process and product simultaneously. Developing a circular businesses model requires radical change and can be viewed as an innovation process [8], where the actors develop, deliver and capture value [9]. These actors need collective learning processes about circular economy and verification that the potential changes do in fact contribute to value creation [10] and document the reduction in environmental footprint. This again requires expert knowledge, parallel development of processes, and knowledge from both industrial based innovations and scientifically based research.

A fundamental principal for developing a circular value chain is the collective effort and co-creation between, both the existing and potential new, actors in the value chain [7]. Such development processes are influenced by the actors' strategic interest, and implementing the solutions often require both interaction and negotiation over time [11].

1.2. Sustainability by design

The discussion in the literature of developing circular business models and 'design for sustainability' are often held at different levels of analysis, namely product level and organizational level. The first fundamental building block of transitioning to a circular economy concern product design and materials [12]. As up to 80% of the climate and environmental footprint of a product are decisions in the design phase [13], the designer's role becomes a discriminating factor in designing products that are designed for and utilize recovered resources [14]. Today more-and-more products are designed for recycling; however, the end user does not always recycle. There are several reasons for this with lack of actors, infrastructure, perceived need, and missing regulations. In addition to developing the new business models with new actors and infrastructure, since decisions during use is determined by customer behavior [15], the product design should engage and encourage the end user to make sound choices during its lifetime and at disposal. That said, achieving a change in customer behavior is difficult [16].

There are different design strategies to reduce the environmental burden, so-called eco-design strategies. At the product level of 'sustainability-by-design', extended lifetime is a key principle for achieving sustainability by reducing the environmental footprint [3]. There is a fundamental distinction between eco-design and circular product design, where the latter is deployed in the field of industrial ecology and based on concepts related to material flows – slowing, closing and narrowing the loop [14, 16] transitioning towards circular business models. For the optimized lifetime strategy there is a recognition that extended lifetime per definition is not an environmental improvement. Nevertheless, for most products an extended lifetime is desirable yet challenged by managers perception and associated lack of exploration of the possibilities, and that this contradict economic interests by reducing revenue and profit [17]. Hence, ibid. call for research that go beyond discussing product design and make steps into actual design practice.

When the goal of a design process is to radically change the function of the unit, for example its environmental footprint, this requires assessment tools and expert knowledge [18]. It also requires tailored methodologies such as developing vision and scenarios [19, 20]. For circular products with extended lifetime the value chain will have to take on a larger responsibility and keep in mind that for products with long technical lifetime the esthetical and social lifetime may be shorter [14] shortening the actual and intended lifetime. Thus, careful considerations of the entire product lifetime and disposal are equally important.

2. Research design

This paper reports preliminary finding from an exploratory case study of an ongoing industrial innovation project with the overall objective of reducing the case product environmental footprint by 50%. The consortium consists of the following actors in the value chain: suppliers, the manufacturer, the distributor, and the waste management company.

While the overall objective of the industrial innovation project is to develop a circular business model, the project is organized through three main goals of developing:

- a new and modularized product with 50% reduction of its environmental footprint.
- a new service that facilitates sustainable behavior, use, and disposal at end-of-lifetime where components are used in several life cycles.
- a new circular business model that take responsibility for the entire life cycle of the case product and contribute to less environmental footprint. This also include a market plan that supports the product and service and ensures a successful implementation in the market.

This paper reports on results from the first main goal and preliminary findings related to the second.

As the overall objective is to reduce the environmental footprint this implies increased value creation for the entire value chain without increasing the resource use through developing a circular business model. In order to achieve a true circular business model, the organizations have to address three underlying challenges in order to succeed with the innovation [21]. A first main general challenge is that organizations lack documentation about statements of reduced footprint which represent a risk of 'green washing' or shifting the problem to other actors in the value chain. Thus, this project must document the actual reduction of environmental footprint throughout the case products lifetime and compare it to the linear business model [20]. The second challenge relates to products being designed for a limited lifetime, and it is a common problem that end users lack information and incentives to ensure the products actual lifetime is utilized. Hence, the product results need to address this challenge through extending the actual lifetime of the product through e.g. reuse and repair [16]. The third underlying challenge is that most manufacturers have little control over a products end-of-life and disposal phase, the decisions made here are held by the end users. However, already in the design phase of the product several of these decisions are made without any review or intent. Such intensions can be design for reuse, design for disposal and design for recycling of components and material.

Solely reviewing the literature will not provide sufficient knowledge into these three underlying challenges, as organizations ways of working inherent operational knowledge of valuable insights. This call for case studies [22] and research that view the entire linear value chains from raw material through to end-of-life disposal with closing of the material flows [23]. This paper reports on the design phase of the case product. Through reviewing theory and practice in parallel, this project aims to contribute to both domains, in line with Van de Ven's [24] arguments.

The success of this project relies on addressing the interface between the domains of LCA, design for sustainability, and value chain development. Accordingly, an interdisciplinary approach is chosen in order to develop and implement a circular business model [7].

2.1. The case product

The case product – one bed –, or the functional unit, has a large volume and consist of two mattresses (component 3 and 4) and one bench (component 1 and 2). The components are assemblies of different materials compounds, and it is used in both private and professional contexts. The material list include latex, hyperflex polyurethane foam, polyester textile, polypropylene, polyamide, cotton, stainless iron, wood, glue, Velcro, and a RFID tag. Packing and instruction manual is made of paper, cardboard, and plastic. The furniture industry's standard lifetime for this type of product is 15 years and this is the 'use phase' time applied in the LCA of the functional unit. Figure 1 illustrate the functional unit and its components (assemblies of sub-components).

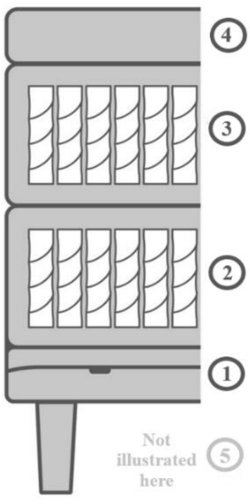

Fig. 1. The functional unit.

2.2. Life Cycle Assessment as methodology

The first of three main goals for this industrial innovation project relates to reducing the case product environmental footprint by 50%. In order to evaluate different reduction strategies, there is a need for a baseline and reference to start discussions from. An initial Life Cycle Assessment (LCA) of the case product is conducted to establish this baseline. This analysis will provide decision support for developing and designing circular products with the objective of influencing customer behavior in line with the second main goal.

LCA is a well-recognized methodology to quantify environmental challenges associated with a product or service [25]. The furniture industry has traditionally used LCA to develop Environmental Product Declarations (EPD), which is an instrument to measure how environmentally friendly one product is compared to another within a product category for a functional unit. Several of the components in the case product have a relative long lifetime and a relative high use of raw material especially for the textiles. A study comparing LCA of European mattresses find that the materials used for manufacturing the mattresses represent the largest environmental footprint, second is the manufacturing processes, third disposal at end-of-life, and to some extent transportation [26]. Environmental footprint from the user phase are minimal and derive from cleaning and repair. Hence, variation in durability and lifetime during the user phase have decisive influence on the case products total environmental footprint. End users' behaviors and choice at disposal and what will happen to the components and material also pay an important role, where mattresses represent almost 10% of the total volume sent to landfills (ibid).

Despite that LCA is a well-recognized methodology for developing circular products, services and business models, the use is still nascent of nature and there is a need for more empirical examples. As of today, there are two main categories of challenges associated with LCA as research methodology where the first is quality issues, and secondly how the methodology is employed [27]. This study contributes with empirical data and report on how the methodology is used as a tool in product development and design of a circular product [28], and how quality of the analysis is secured. Fig. 2 illustrate the research design.

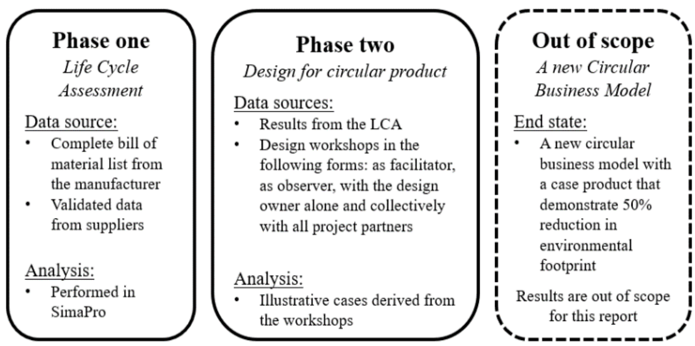

Fig. 2. Research design.

3. Results and discussion of preliminary findings

Attempting to answer the research question of *how to develop more circular products and new business models enforcing sustainable customer behavior,* this study starts with establishing an initial baseline for the functional unit, in order to validate a 50% reduction in environmental footprint of the final conceptual design (new prototype). This is achieved through conducting an LCA in the SimaPro software. The following sections will report on how the LCA was conducted and how the results from the LCA were utilized in the design phase. The calculations done in SimaPro follows ISO 14040 covering the production phase, use phase, transportation, and disposal.

3.1. The results from the LCA

Fig 3. shows the case products five components (which are assemblies of sub-components) and their environmental footprint for the top five out of the total of eighteen different categories of environmental footprints, relative to a European average for one year per category. The categories not included in the figure, due to relative less footprint, are: climate change, ozone depletion, terrestrial acidification, marine eutrophication, photochemical in oxidant form, particulate matter format, terrestrial ecotoxicity, ionizing radiation, agricultural land occupation, water depletion, metal depletion and fossil depletion.

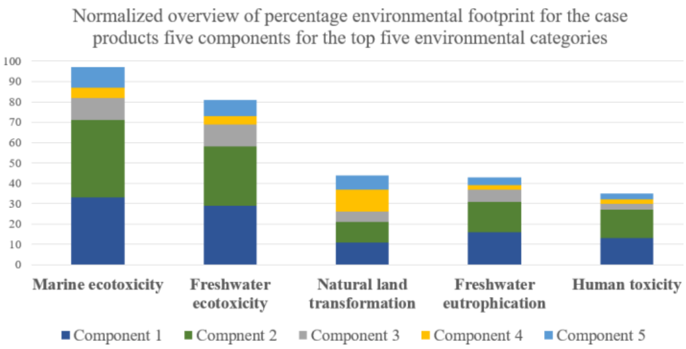

Fig. 3. Normalized overview of impact on top five environmental categories.

The relatively high environmental footprint for marine ecotoxicity derives from the metal casting processes of the functional unit metal components. The metal contains ferronickel, where the treatment process to remove slag associated with melting of nickel evidently contribute to the majority of the negative impact on nature through toxins. The metal component is part of the assembly in both component 2 and 3, thus amounting to more than half the impact on freshwater ecotoxicity.

For 'use of natural land transformation', which is the category that has the third highest environmental footprint it is component 4 that has the largest negative impact. The reason for this relates to the production of natural rubber used in latex and the manufacturing of polyester used in textiles.

For the fourth category with the highest negative impact, freshwater eutrophication, it is again the metal components that gives the largest impact. Manufacturing of the polyurethan-foam in component 5, and textiles and latex in component 4 also contribute negatively. For some of the textiles that have negative impact they are chosen for their superior quality and durability compared to materials with less negative impact per unit. Arguably, in a life-time perspective they will still not surpass the total negative impact of choosing the textiles with less initial negative impact as the component will have to be replaces more frequently increasing the total negative impact.

3.2. Analysis of the findings from the LCA

The results from the LCA form the baseline not only for the functional unit's environmental footprint, but also a baseline for identifying the most problematic components. In a design process these insights may be used to questioning the specific components, their function and their choice of material and design in order to arrive at more environmentally friendly choices. Results were also used to develop scenarios for choice of materials, lifetime, and disposal. LCA are associated with degrees of uncertainty. Reducing uncertainty were done through asking raw material providers and sub-suppliers to verify the input data, material processing processes, energy sources used, and providing material declarations. Lastly, the results provide a reference and target measures new design solutions should restrain to and be validated against.

The analysis of the LCA identified three prioritized components and materials that are problematic and should be addressed in the design phase:

- **Steel** used for the springs impact fresh water negatively. Ways of addressing this issue can be found in the manufacturing processes of steel (percentage of recycling, origin of raw material). Design solutions that use less avoid steel, reuse, or recycle, or avoid the steel component.
- **Textile** with a mix of cotton and polyester.
- **Latex** used in comfort components.

Both for the textile and latex components their choice of material is embedded in technical and quality measures of the case product, which increase the complexity of considerations needed in the design phase.

3.3. LCA findings as input to the design phase

Achieving the ambitious goal of reducing the case product environmental footprint by 50% require the development of a new mindset and tools for circular design of products with a large volume and long lifetime. This is a complex exercise as the solutions not only need to take into account the impact your value chain has an influence on, but also the user and disposal phase. Since the lifetime of the functional unit is set to 15 years the solutions also need to attempt to address new requirements in the value chain or imagine actors missing today. The entire value chain should take part in developing these solutions.

The design phase employed in this industrial innovation project is illustrated in fig. 4.

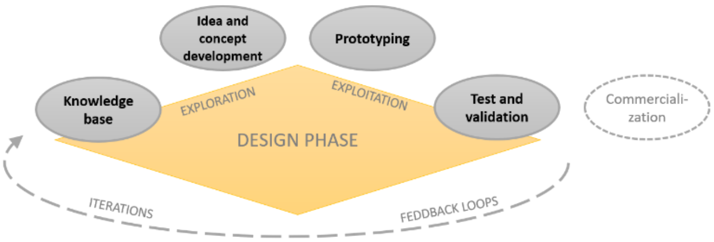

Fig. 4. Design phase.

3.4. Preliminary findings and illustrative cases from the concept development phase

As this paper reports on the ongoing industrial innovation project and how LCA can be used in conceptual design of circular products on the quest of developing circular business models and customer behaviors, these preliminary findings are presented as illustrative cases.

Illustrative case – knowledge base. The manufacturer of the case product had the following statement following presentation of results from the LCA: "*It would be nice if we had someone from the metal industry, maybe one of our suppliers, with us in this project*." This statement demonstrates that knowledge from the LCA incentive the manufacturer to both work closer with its suppliers, but also to invite them into their idea and concept development. Another example from one of the suppliers: "*When one of the designers came along to view our production line, he saw some deliveries to a different customer in another segment, and he started touching and studying the component. – Oh, I haven't seen this before, are you able to manufacture this?! he asked with excitement. So now we have developed a concept that requires much less manufacturing and is designed for disposal*." Having the waste management company in the consortium played an important role in the design phase. They held knowledge several of the suppliers and the manufacturer did not access before, but now see a new value of.

Illustrative case – idea and conceptual development. What is evident from statements from all consortium participants are that the physical workshops with visits to each other's facilities paid an important role in their understanding of existing components and their manufacturing processes. These visits were enablers for envisioning radically new solutions, opportunities and possible design improvements, substitutes, or changes. One specific example and statement concern a component that traditionally on default is designed and manufactured in steel. "*Since we know that steel has the highest negative impact on environmental footprint as a result from the LCA, we questioned if this sub-component could be made by wood instead. We have now tested the component and we can manufacture this in wood! This is a direct consequence of this project; we have a new terminology and question all decisions related to use of problematic material. On top of that, the component is now much cheaper to produce*."

Illustrative case – Prototyping, test and validation. One of the suppliers have a separate ongoing innovation project where they collect astray plastic. Plastic per say is not necessarily a problematic material, however astray plastic is, the project was presented for the manufacturer part of a workshop. Following the workshop, the material was tested and made into a prototype. This validated that it met quality requirements and became novel use of astray material, reducing overall environmental footprint of the case product.

Illustrative case – Commercialization. The project also provides evidence that the LCA results has important implications for the design and commercialization phase in several ways. First example is related to knowledge from the LCA and the following statement from a supplier with a component of high negative impact. "*We want to be part of this project and contribute to finding new solution. Worst case we have to change our business model in order to still be able to deliver components. In the case we did not take part, we risk that they disregard us as a supplier without any discussion, now we can be part of finding the solution and securing our future as a supplier*. […] *If this material is problematic for this manufacturer it will also be problematic for others. If we are able to find new business opportunities, we have a competitive advantage compared to competitors*." Another example illustrates the change in mindset "*To be honest, I have to admit that at first we took part in the project only because we were asked. Now we have understood the great importance of this project, not only for us as supplier, but also because we can make significant contributions improving the footprint. Not only for this customer, but at large. Improving competitiveness as environmental requirements are set by both customers and regulators. This will influence everything we do.*"

4. Further research

This ongoing industrial innovation project will run until Q1 2023, nevertheless it has already identified several key areas that deserve further inquiry. The following list include the most promising:

- There is a lack of standardized reporting for sustainable products within the furniture industry.
- When the objective is to reduce a product or service environmental footprint the reduction strategies highly influence the design processes. Designing solutions that address more than one category is critical to avoid shifting the problem from one to another category.
- Estimating lifetime for organic versus synthetic material is challenging in several was.
- Complex and long value-chains make documenting environmental footprint challenging. There is a lack of standardized reporting tools for validating data.
- When designing products that aim to change customer behaviors, knowledge about the customer experience, preference and true behaviors is determining for design.

5. Concluding remarks

Even though this project is ongoing there are still several conclusions to be drawn upon the empirical evidence. One of the key findings in this paper is that the entire value chain should take part in developing the solutions. This point cannot be stressed enough, as suppliers' sub-processes and choice in energy source have a direct and high influence on the case products environmental footprint. Hence, a first conclusion is that all actors in the value chain should have an embedded role in developing new circular products and business models.

Co-creation and collective design process require that core stakeholders are involved, and their needs addressed. There is a principal difference between optimizing based on existing material base, e.g., usage of steel, and new designs where some material is left out and others included. In other words, this study observes a tension between incremental and radical design in the processes. It seems logical that the actors are drawn towards incremental change in the beginning of the process and that acceptance and openness towards more radical change increases based on knowledge and maturity in the project. Here the physical visits to each other's facilities played an important role, especially in shifting and challenging pre-determined mind-sets. Transitioning to a circular economy requires radical changes in mind-sets. Preliminary findings demonstrate that this project will serve as an example that it is possible, and profitable, to develop circular products and business models with a holistic plan to reduce overall the environmental footprint.

This project answer UN SDGs 3, 8.4, 9.4, 12.2, 12.4, 12.5 and 13.3. The project takes an interdisciplinary approach including the entire value chain in a knowledge-based development and decision process. This secure better and more efficient usage of global resources, industrial and labor related processes – designing a circular product.

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