Circular Material Library. An Innovative Tool to Design Circular Economy

Maarit Virtanen\textsuperscript{a}, Kati Manskinen\textsuperscript{a}, Sauli Eerola\textsuperscript{b}
\textsuperscript{a}Lahti University of Applied Sciences, Finland
\textsuperscript{b}Muovipoli Ltd, Finland
*Corresponding author e-mail: maarit.virtanen@lamk.fi

Abstract: Circular economy requires re-thinking and re-designing of products and services to enable product reuse, recycling and cascading. The use of secondary materials is an essential part of circular economy and it is in a central role in EU’s action plans. This paper examines, how a Circular Material Library can be used as tool of user oriented design to promote regional circular economy, innovation and competencies in companies. The Circular Material Library differs from the existing material libraries in that it will focus on available recycled materials. Due to the increased understanding of materials, new symbiosis products and industrial symbiosis networks can be created. Especially SME’s would benefit from this public tool.

Keywords: circular economy, design, material library, recycled material

1. Introduction

The circular economy (CE) is a concept which has received growing attention in recent years. CE aims to increase resource efficiency by closing the loop and maintaining the product, material and resources in the economy as long as possible, and minimizing the generation of waste. Recycling of materials plays a significant role in CE. The European Union Action Plan for Circular Economy (2015) addresses the need to develop markets for secondary materials, as they still account for a small proportion of materials used. Currently, approximately only 40% of the waste produced by EU households is recycled (COM, 2015). In addition, there is a huge potential to increase recycling of material especially amongst small and medium sized companies (SMEs) due to the fact that only 25% of their waste material is sold (Circular Economy Factsheet, 2016).

Recyclability of waste material depends on the type of material. Some waste materials are recyclable until a certain point and some are even unrecyclable (Ghisellini et al., 2016). Materials such as metals, glass and paper have a long tradition in recycling. The properties of these materials also enable remanufacturing. However, some waste materials contain harmful elements which may prevent their reuse. In addition, it is notable that during recycling processes materials may be mixed...
with each other, as is the case with various plastics, which influences the processing properties of these materials. Hence, closed material loops increase the importance of material knowledge.

It is evident that materials have an essential role in design and they influence many aspects of product design. In order to provide designers a hands-on resource to understand materials and related properties, several material libraries have been established (Akin and Pedgley, 2016). However, to the best of our knowledge, none of them focuses on recycled materials and their properties. This paper presents a concept called Circular Material Library, which differs from existing material libraries in that it aims to facilitate regional industrial symbiosis, and also in that it focuses on recycled materials. Industrial symbiosis is a means of promoting circular economy and can be defined as (Ellen MacArthur Foundation, 2016) the exchange of materials, energy and water between companies, so that the waste or by-product of one company becomes a resource for others. Industrial symbiosis is based on commercial agreements between public or private actors, which benefit from resource savings, while at the same time benefiting the environment.

Symbiosis products are product systems with multiple waste or residue streams from different industries. Industrial symbiosis products have a high potential to improve material efficiency and residue utilization. However, symbiosis products are also challenging in that they require cooperation between industries, a profound understanding of material properties, and, not least, an enabling institutional approach with appropriate market incentives and regulatory instruments. According to Watkins, Husgafvel, Pajunen, Dahl and Heiskanen (2013), a more holistic thinking by both regulatory authorities and industries is needed to overcome industrial barriers. This requires, furthermore, the design of new sustainable approaches in public-private collaboration.

2. Methods and approaches

2.1 Design in circular economy

Transition towards CE requires transformation from product-oriented business models to more service-oriented and result-oriented models (Peck, 2016). In product-oriented business models the principle of companies is to maximize the number of products sold and only some minor additional services are added, whereas in service-oriented business models the companies are being paid for the service offered, and the materials which are used for providing the service become cost factors. In result-oriented services there is no pre-determined product involved, but the client and the provider agree on the wanted service or result. (Tukker, 2015). Therefore, in such models products are designed as cost- and material-efficiently as possible. The design of the product influences the way the whole value chain is managed and can enable circularity. (De los Rios and Charnley, 2016). The system transformation means that companies need to build competencies in circular design to enable product reuse, recycling and cascading (Webster, 2015), but also an increased understanding of social behaviour is needed.

An essential part of CE is to design products that last longer, which means that products are not only used longer but they can also be reused, repaired and remanufactured. This requires a new kind of design thinking, which takes into account the whole product life and circularity of both product parts and materials. Six design strategies have been identified to reach these goals (Bakker, den Hollander, van Hinte and Zijlstra, 2014):
1. Design for Product Attachment and Trust is the principle that is perhaps the most difficult for the designer, as it requires foresight for designing products that people will like and hold on to for a long time;  
2. Design for Product Durability means creating resilient products through the physical design and choice of materials;  
3. Design for Standardization and Compatibility enables, for example, replacing parts or expanding the product so that the parts not only fit the product itself but also products of different brands;  
4. Design for Ease of Maintenance and Repair facilitates the easy maintenance and lifetime expansion of products;  
5. Design for Upgradability and Adaptability enables the modification and expansion of products according to different users’ needs and changing contexts;  
6. Design for Disassembly and Reassembly facilitates the eventual recycling of the product and, even more importantly, remanufacturing of new products with parts that have been used before.

Alongside circular design, there is an increasing interest in material driven design, in which new, mostly recycled materials are the driving force of innovation. Material driven design can be characterized (Chawla, 2016) as design led by material considerations and limitations, and as an intersection of science and design: the use of novel materials requires thorough studies on material properties. Examples of material driven design often include utilization of different wastes or side streams like 3D printing of waste nylon, demolition waste, or natural products. However, material driven design also has wider implications like the development of new technologies to enable product manufacturing. Material selection has a central role in design decision-making and it influences many aspects of product design. Materials can stimulate designers to create new forms and even new types of products. (Akin and Pedgley, 2016.)

2.2 Material Libraries

Material libraries have been established to help designers and product developers to choose best materials for a certain object, and also to rethink and reimagine projects together (Dent and Sherr, 2014.) According to a survey by Akin and Pedgley (2016), the main roles of material libraries are to provide a tangible source of inspiration through physical samples; to act as a catalyst for discussion between design project stakeholders; and to facilitate design appraisal from different sensory perspectives. Most libraries have been established within educational institutions to support materials and design education. Other important roles for material libraries include supporting research and development activities and fostering communication between stakeholders, such as companies, researchers and users. The latter was also the area in which many libraries were planning to invest in the future.

The business models of material libraries differ, but commercial libraries often provide advisory and consultancy services for their clients. An interesting example of existing libraries is Materialbiblioteket in Stockholm. Unlike most libraries, Materialbiblioteket has no digital database on material properties and the material collection comes directly from companies. The companies provide samples of various types for display and innovation, and further information on their properties and availability. Companies pay an annual fee to have their materials on display. The main
user groups in the library are architects and industrial designers, who utilize the library at the very beginning of the product design process before material selection has been done. The library collection is open for touching and creating mood boards to foster innovation within stakeholder groups involved in the product design process. (Ek, 2016.)

Figure 1. Material collection at Materiabiblioteket in Stockholm, Sweden.

The importance of stakeholder cooperation is also reflected in the functioning of Material ConneXion, which is the world’s largest subscription-based material library. Besides the constantly growing collection of thousands of commercially available materials, Material ConneXion offers consulting services, with several global companies as their clients. The aim of consultation is to help clients innovate and also to educate them about sustainability values by seeing the overall impacts. As the company Vice President states, there are no sustainable materials, but only sustainable uses of them. (The New York Times, 2015.)

2.3. The Circular Material Library Concept

The Circular Material Library will act as a tool to support industrial symbiosis and to promote the use of recycled materials. The concept of the library has been designed as a multidisciplinary effort together with companies and other stakeholders. Recycled materials are often included in the collections of material libraries, but alongside virgin materials. The Circular Material Library collection will include both already industrially used recycled materials and new materials that are still at a pilot stage. The selection aims at assisting in different kinds of company needs, so that designers can pick both a well-known recycled material to replace virgin ones in existing value chains or they can innovate new products with novel materials. Likewise, students can explore the possibilities of new materials as a basis for their products and prototypes. The physical library includes both material samples and prototypes made of recycled materials.

The Circular Material Library is created together with students from materials engineering, environmental engineering, information technology, the Institute of Design as well as business studies. The materials and environmental engineering students focus on library materials by
collecting information and samples from companies, analysing the samples, and planning material specifications. Information technology students make the digital database and implement its visual appearance. Design students visualize both the physical and the digital look for the library, while business students plan the future business model for the library. In addition, students make product prototypes both on individual courses on materials engineering and design, and as a part of multidisciplinary Circular Economy Path studies.

The design students have approached the physical library from a service design point of view by first thinking about the goals of the library and different potential users. Another aspect in the work is information design, which further improves the usability of the library. In practice, this can mean, for instance, colour coding and symbols for the different material classes and a uniform look for the digital and physical library. Especially company needs are taken into account in the planning of the digital library, with the aim of creating material specifications and search functions that allow users...
easy comparison of materials. In addition to material information and samples, the library provides a physical space for meetings and discussions.

3. Circular Material Library

The Lahti region aims at becoming an internationally interesting and rapidly reacting region for the development of circular economy, as stated in the Lahti Declaration of Circular Economy (2016). The signatories of the declaration commit themselves to, for example, taking circular economy into account in public procurements and investments; investigating the industrial-scale value chains in circular economy; and developing new business. The Circular Material Library supports regional goals by acting as an innovative tool for companies, students and other stakeholders, and by facilitating industrial symbiosis.

So far, existing industrial symbioses have been based on big companies consuming large amounts of materials and energy. SMEs can have less incentive and resources for reducing their environmental impact than larger, resource-incentive companies and can also be more sceptical of the benefits. (Puente, Arozamena and Evans, 2014.) Nonetheless, circular economy provides business opportunities for SMEs throughout the value chain, and SMEs are already active in circular economy activities like recycling, repair, and innovation. The Lahti region in southern Finland is characterized by a large number of small and medium sized companies. Although there are examples of industrial symbiosis in the region, there are still many unused opportunities in this area. Industrial symbiosis is hindered by the lack of information on the availability of materials and their quality and properties. (Autio, Medkova and Cura, 2015.)

A prerequisite for industrial symbiosis is that companies share information about their materials and side streams, understand the potential of cooperation and are willing to discuss the opportunities with others. The Circular Material Library provides a channel to share information and to begin discussions on cooperation. Information about regional material flows has been collected from companies in the course of library development, and the library’s material samples mainly come from the companies in the region. Another goal is to build a physical library from locally available recycled or composite materials. The library will also provide a physical space for stakeholder discussions and a channel to reach different experts.

Previous studies show that the most important research areas related to materials technology were basic research and material development, the recycling and recovery of materials, characterization and testing, process development and material efficiency (Author, 2014). Also, a continuous search to find alternative materials to ensure competitiveness was observed. However, finding adequate information about new materials can be challenging, particularly for smaller companies. The quality risks related to the use of recycled materials can also hinder their use especially in totally new products and value chains.

The use of recycled materials is often hindered by the lack of information in the product design phase. The direct benefits of using recycled materials can be relatively small compared to their “time-to-market” costs and risks. For example, the price advantage of recycled materials is often small compared to virgin materials. The uptake of recycled materials in products has similarities to new, radical material innovations. A successful uptake of new materials, like nanomaterials, is more likely if they are integrated into the existing value chains. If an entire value chain has to be created, the time to market is likely to be too long or the return on investment too low especially for smaller companies. (Manoharan, 2008.) The Circular Material Library provides a way to assess the properties
Circular Material Library: An Innovative Tool to Design Circular Economy

of different materials, and also offers information about their availability. Ideally, the Library would in the future be linked to an online material shop through which companies could directly buy or sell resources.

With circular economy, the product and service design targets are changing, because of the necessity to innovate while optimizing the use of resources and energy and closing the loops. The design skills needed include a deep knowledge of materials science, engineering techniques and operational processes, as well as service design skills and understanding of user perspectives. (De los Rios and Charnley, 2016.) The understanding of a product’s environmental impacts throughout its life cycle requires input from many stakeholders, including the supply chain, and often circular design also requires management interventions (Prenderville, O’Connor and Palmer 2014).

An important aspect of the Circular Material Library is to connect especially smaller companies with experts from different fields that can assist with, for example, research and development of circular economy business models. As the library is related to a higher education institution, companies have an easy access to services provided by the institution and its partners. The Circular Material Library is designed so that it is adaptable for different purposes and situations related to innovation and product design processes by companies, students and designers. The physical library units are movable, so that the library with a selected set of samples can be used at, for example, different events or at company workshops. This supports the aim of the library to foster industrial symbiosis and cooperation between different actors.

4. Conclusions and Discussion
The use of secondary materials is an essential part of circular economy and it is in a central role in EU’s action plans. However, there is a lack of comprehensive knowledge about recycled materials properties and potential uses. The Circular Material Library can be used as an innovative tool of user oriented design to promote regional circular economy and competencies in companies. Especially SME’s would benefit from this public tool.

The physical and digital library collection supports product design processes in companies. It promotes both the use of recycled materials to replace virgin ones in existing value chains and the innovation of new products with novel materials. Due to the increased understanding of materials, new symbiosis products and cooperation networks can be created. Hence, the Circular Material Library supports the transition towards circular economy. However, it is worthwhile to note that the closing of material loops is a complex phenomenon, where in real life e.g. symbiosis products are further mixed with other materials and new recycled materials are created. Therefore, continuous research of recycled materials is required.

References

Akin, F. & Pedgley, O. (2016). Sample libraries to expedite materials experience for design: A survey of global provision. *Materials and Design*, 90, 1207–1217. http://dx.doi.org/10.1016/j.matdes.2015.04.045

Author. (2014). Journal Article.

Autio A., Medkova, K. and Cura, K. (2015). Students Learning Circular Economy with Companies in the REISKA Project. Presentation at World Resources Forum 2015, October 11-14 2015, Davos, Switzerland. Unpublished.

Bakker, C., den Hollander, M., van Hinte, E. and Zlijistra, Y. (2014). *Products That Last: Product Design for Circular Business Models*. TUDelft.

Chawla, P. (2016). The Future Belongs to Design Driven by Materials. Presentation at The Disruptive Innovation Festival (DIF). Online event 7-25 November 2016. Available at: https://www.thinkdif.co/about

Circular Economy Factsheet. (2016). European Commision Factsheet: Circular Economy closing the Loop From Waste to Resources. from: http://ec.europa.eu/priorities/sites/beta-political/files/circular-economy-factsheet-waste-to-resources_en.pdf, accessed 14.12.2016.

De los Rios, I. & Charnley, F. (2016). Skills and capabilities for a sustainable and circular economy: The changing role of design. *Journal of Cleaner Production*, in press. http://dx.doi.org/10.1016/j.jclepro.2016.10.130

Dent, A. & Sherr, L. (2014). *Material Innovation: Product Design*. Material ConneXion Inc.

Ek, S. (2016). Personal communication, Project Area Manager Materialbiblioteket. 13.12.2016

Ellen MacArthur Foundation. (2016). *Effective Industrial Symbiosis*. Available at: https://www.ellenmacarthurfoundation.org/case-studies/effective-industrial-symbiosis

European Commission. (2015). Turning recycled raw materials into business opportunities. Retrieved at: http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8589&lang=en

Lahti Declaration of Circular Economy (2016). Retrieved at: https://www.lahti.fi/AjankohtaistaSite/UutisetSite/Documents/laahden-kiertoulousjulistus_10-5-2016-suomi.pdf (in Finnish).

Manoharan, M. (2008). Research on the frontiers of materials science: The impact of nanotechnology on new material development. *Technology in Society*, 30(3–4), 401–404.
MaterialDriven. http://www.materialdriven.com/
Prendeville, S., O’Connor, F. and Palmer, L. (2014). Material selection for eco-innovation: SPICE model. Journal of Cleaner Production, 85, 31-40. http://dx.doi.org/10.1016/j.jclepro.2014.05.023
The New York Times. 2015. Behind the Scenes in Luxury. Retrieved at: http://www.nytimes.com/2015/12/02/fashion/behind-the-scenes-in-luxury.html?_r=1
Watkins, G., Husgafvel, R., Pajunen, N., Dahl O. and Heiskanen K. (2013). Overcoming institutional barriers in the development of novel process industry residue based symbiosis products – Case study at the EU level. Minerals Engineering, 41, 31–40. http://dx.doi.org/10.1016/j.mineng.2012.10.003
Webster, K. (2015). The Circular Economy of Material Flows. Ellen MacArthur Foundation.

About the Authors:

Maarit Virtanen, M.Sc. (Admin.), is a Research, Development and Innovation Specialist at Lahti University of Applied Sciences. Her main research interests are circular economy, industrial symbiosis and circular business models.

Kati Manskinen, D.Sc. (Tech) is a Research, Development and Innovation Director at the Lahti University of Applied Sciences. Her main research interests are circular economy, resource efficiency and especially utilization of industrial by-products.

Sauli Eerola, D.Sc. (Tech.) is working as the CEO of Muovipoli Ltd specialized in R&D services of plastics technology in Finland. His main interests are in innovation tools and environmental issues especially in the field of materials technology.