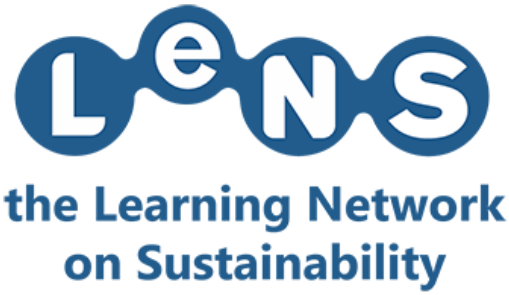

DESIGN FOR CIRCULAR ECONOMY - A RE-THINKING PROGRESS IN THE WAY WE MAKE, BUY AND USE THINGS

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ABSTRACT

Circular Economy refers to an industrial economy that is aimed at restoration and regeneration by careful design. It requires a re-thinking progress to explore how we can re-design the way our economy works and how we can rethink and redesign products that we make, consume, use and discard. However, the concept is still relatively new and how we can introduce the concept in design education and what kinds of tools and methods can be used are still not well known. This paper is to share some teaching experience of Design for Circular Economy and its design process, and the tool Sustainable Product Matrix will be introduced. Two student projects were demonstrated how this tool helped them to gain deeper insights of sustainability problems and create a comprehensive solution. Finally, the challenges and opportunities of Circular Economy will be discussed, and some suggestions will be provided for this new kind of design thinking and doing.
Key Words: Circular Economy; Circular design; Cradle-to-Cradle; Life Cycle Thinking; Recycling; Sustainable development

1. INTRODUCTION

As global warming and climate change are getting more serious, the education of the young generation of designers to understand and apply sustainability development concepts in practice is important.

One recent concept of sustainability development is Circular Economy (CE), which refers to an industrial economy that is aimed at restoration and regeneration by careful design. The concept was derived from varies concepts such as regenerative design, performance economy, Industrial Ecology, Cradle to Cradle design, lifecycle design and Biomimicry (Ellen McArthur Foundation, 2013; Kalmykovaa et al, 2018; Korhonen et al, 2018). The goal is to keep products, components, and materials at their highest utility in a closed-loop, at the same time, generate social, economical and environmental values. It requires a re-thinking progress to explore how we can re-design the way our economy works and how we can rethink and redesign products that we make, consume, use and discard.

The Ellen MacArthur Foundation (2013) suggests four main principles of CE include:

- Design out waste - design the components of a product to reduce wastage
- Build resilience through diversity - build diverse systems are more resilient in the face of external attack.
- Rely on energy from renewable sources - Systems should ultimately aim to run on renewable sources.
- Think in 'systems' - understand the parts and their relationships, how they are influence one another is important.

However, the concept of designing for CE is still relatively new, how can we introduce the concepts and what kinds of tools and methods can be used are still not well known. Moreover, the concept focuses more on the material and product production and consumption, but lacking the use and behaviour aspects. The author argues that design strategy for CE will not be successful without changing the consumption patterns and consumers' behaviours.

This paper is to share some teaching experience of Design for Circular Economy of an undergraduate module in Industrial Design discipline. It will start by discussing the design process for CE and followed by the tools and methods it used, especially the "Sustainability Product Matrix" is introduced. Two student projects will be demonstrated how these tools and methods were used to develop circular solutions. Finally, some challenges in Design for Circular Economy will be discussed with some suggestions is provided.

2. TOOLS AND PROCESS FOR DESIGN FOR CIRCULAR ECONOMY

This section is to describe the design process and some design tools and methods used in the teaching module to develop a better solution that eliminate waste and benefit to the environment and society in a circular economy.

2. 1. Design process

The class was a Design for Sustainability module in Year Four undergraduate Industrial Design programme. The module aims to offer students insights into the environmentally unsustainable aspects of consumer culture, and into the role product and industrial design play in this context. By introducing alternative concepts, and through design exercises, students develop, test and describe alternative design concepts with improved environmental impact. The module also aims to strengthen students' critical thinking and their ability to put forward well-structured arguments.

Six groups of students with each group of four students worked together. They were required to design a product and a system for different family contexts, for example, a family with a young child, an elderly living alone, two young women living together, a university student living in a dormitory.

The design process adopted the Circular Design concept with some modifications. Circular Design is a design concept derived from CE. A Circular Design tool was developed by Ellen McCarthy Foundation teamed with the design consultancy firm IDEO (Reigadoa et al, 2017). It employs the design thinking approach to guide "innovators, entrepreneurs and corporate change-makers" to explore new ways of "creating solutions for the circular economy that give businesses a competitive edge and are regenerative for our world." (MacArthur & IDEO, 2019)

The Circular Design Guide provides comprehensive design tools and methods to develop and implement circular innovation. but it did not suitable for a 14 weeks module so we only adopted the design process. In Circular Design Guide, the design process includes Understand, Define, Make and Release (MacArthur & IDEO, 2019). Nevertheless, Design for Sustainability and Circular Economy is about choice and trade-off - choosing the best alternative ways to achieve sustainability, either the choice of material or energy use, or the production methods, the way of doing business or manage the end of life of a product. It is important for designers to explore different alternatives to make better decisions. Hence, we modified the design process as Understand, Define, Explore, Make, and Release as the following in Table 2.1.

[Table 2.1] Design process in Design for Circular Economy)

Design process	Activities	Tools and methods
Understand	Understand user needs Research of the product life cycle Research materials Research existing products and competitors	User-centred research methods Online research of materials

Define	Analyse user research Analyse existing product system and competitors Define user needs Identify stakeholders Define sustainability problems and focus on which problem(s)	Stakeholder map System map Sustainable Product Matrix Design brief
Explore	Explore different alternatives and try to use the less harmful and most beneficial choices	Sustainable Product Matrix
Make	Brainstorming and concept generation Imagine new partnership/stakeholders Develop ideas and concepts	New stakeholders and System map Rapid prototyping
Release	Test and implement the design solutions	Story board Prototype Presentation

The Exploration stage is important since after designers have done research on user needs, materials and product life cycle, they need to explore the best alternatives in the choice of material, energy, way of production, consumption, use and discard that can reduce the environmental impacts and provide benefits to a wider context. This part goes beyond just concept generation but requires designers to gain deeper insights in different aspects to make better decision making. Hence, exploration in Design for Circular Economy is arguably an essential part in design process. The concepts can be developed during and after the exploration process.

In order to help designers to better understand the complex problems in product lifeless as well as identify design opportunities, a tool called "Sustainable Product Matrix" was developed and it will be described in more details in the next section.

The students started by doing research according to different family contexts, they interviewed the users and discovered their needs and the sustainability problems in that particular context. In order to provide more understanding of existing products and technologies, the students also conducted competitor research. They then used the tools and methods described in the Table 2.1 to analyse the problems, identify opportunities, general design concepts and build the prototypes.

2. 2. Tools and methods

The tools and methods used in the module including many commonly used methods in design process such as interview and field study for user research, brainstorming for generating ideas, and rapid prototype for user test and implementation, as well as business model canvas for developing sustainable business. Stakeholder Map and System Map, both are tools for Product-Service-System Design (PSSD), were also used for identifying stakeholders and their relationships in the system, as well as to understand how the product is produced, manufactured, delivered, used and discarded in the existing system. Both of these tools can also be used for developing new solutions. In this section, I will focus on introducing a tool specially developed for analyzing the sustainability impacts and exploring new alternatives for circular economy.

In CE, the knowledge of materials flow and the whole production and consumption process are essential to improve the efficiency and effectiveness of materials and recycle process (Kalmykova et al, 2018). Life cycle thinking is required to analyse the whole product life cycle from the sourcing of primary materials to the disposal of waste. According to Lehtinen et al (2011, p.5),

"Life cycle thinking enables us to identify both threats and opportunities in the life cycle of the product or service; to understand the trade-offs between the impacts at different stages of the life cycle, and to communicate the challenges and options to others. …It is also useful in finding out where in the life cycle the major impacts arise as a starting point for discussing where the innovation targets could be set."

Life cycle thinking helps designers to identify the major impacts and they would become design opportunities for new innovations. It is vital in design for sustainability and circular economy as the whole cycle of a product and its subsequent impacts can be examined and understood, which can help designers to make better decisions in developing the products and redesign the systems in a more sustainable way, as well as to avoid waste and damage during the process.

Life cycle thinking is also related to the concept of "Cradle to Cradle" design which suggests to designing product in a way that it can be easily re sued or recycled at the end of their useful life, and the materials can be go back to the manufacturing process for new products (Braungart and McDonough, 2009). The Cradle to Cradle concept proposes to adopt ecological system that waste can become food and it emphasizes on eco-effectiveness, that is, make product good for upcycling and beneficial to the environment rather than just eco-efficiency on solely develop the product 'less bad' to the environment. It suggests that most products are composed of technical and biological types of materials, so designers can design accordingly for easily to be reused and recycled and it can avoid waste at the end of life. Cradle to Cradle design approach is a radical innovative design approach as it requires designers to rethink the existing product design and consumption process to redesign a new solutions.

Life Cycle Assessment (LCA) is a tool for analyzing the materials and energy use during the product life cycle (Lehtinen et al, 2011) and many digital tools have been available. However, LCA is very complex and highly technical (Lehtinen, et al, 2011), it requires the designers or engineers to know specific material components so as to calculate their impacts of the environment accurately, but most of the product materials do not include detail information unless it is provided by the manufacturers. Most of the products are also comprised of various materials and it is difficult to trace back the sources and the impact during the production, consumption, use and end of life. The terms of data usage also differ from database to database, it is very difficult to find relevant information for selected uses (Lehtinen, et al, 2011).

In addition to the above problems, LCA is mainly focused on the materials, but the economical and social impacts during the product life cycle is lacking. The tool only provides numerical information on the materials but how significant the impacts of the environment are and the information of social impacts is completely ignored. However, to achieve sustainable development by CE, the product or service should not only use a 'less bad' approach but provide mutual benefits and values to both the companies, the environment and the society. In our existing design process, this comprehensive way of design thinking is lacking and that is why many design solutions are partly contributing the environmental problems today. For instance, the invention and creation of plastic bags were to help people easily to carry things but it lacks of consideration of the side effects to the environment and the society. Moreover, the LCA is missing the cultural and contextual factors as the raw materials, production, consumption, use and discard are contextual base, for example, the energy of transportation from overseas will create more CO2 then using local source, and the energy it produces can be wasted. So only numerical information is not sufficient for designers to develop a truly environmental products for sustainable development.

According to UNESCO (2019), sustainable development includes four dimensions – society, environment, culture and economy, which are intertwined and not separated. Therefore, only focus on environmental gain is not sufficient. However, during the whole product life cycle, the economic, social and environmental impacts are complex and it is difficult for the designers to know and identify the problems and opportunity to change. There are many tools for sustainability design and design for circular economy, but few of these tools includes all of the three areas for sustainable development. These existing tools are not sufficient to help designers to examine and gain comprehensive understanding and insights of the environmental problems and its impacts.

In this regard, a tool called "Sustainable Product Matrix" was developed which was based on the concepts of product life cycle and sustainable development, where a sustainability design should consider economical, social and environmental benefits. The purpose of the matrix is attempting to help designers to research and identify the problematic areas during the whole product life cycle regarding sustainability. The Sustainable Product Matrix (Table 2.2) includes two parts: on the left side is the product life cycle process and the top row comprise of the sustainability impacts including material, energy, water, economical impacts, social impacts and environmental impacts . The environmental impact is ranged from 1 to 5 being 1 is the lowest impact and 5 is the highest impact. So the higher the number, the more sustainability problem. Other than putting the numbers on the matrix, they can also mark down some keywords to help them to gain more ideas of the particular problems. The matrix helps designers to understand the relationships between the product life cycle, the resources and the impacts it creates.

[Table 2.2] Sustainable Product Matrix

Process	Materials	Energy	Water	Environmental Impact	Economic Impact	Social Impact	Total
Pre-production							
Production							
Packaging							
Distribution							
Use							
End of life							
Total							

The tool requires the designers to conduct some research to understand the impacts of a product from its raw materials to its end of life. It aims at helping designers to gain insights without focusing on too much detailed and exhausted information. It guides the designers to consider the material flow, production, delivery, consumption, use and end of life and their impacts in a clear and comprehensive way. It is suggested to use in a group to divide the workloads.

The designers can start by researching the raw materials of an existing product and the impacts of the social, economical, and environmental aspects during the pre-production phase to the end of life phase. For example, if the raw material is plastic, they should research about the sources of the material and the impact it made during the whole product life cycle. Then they mark the number from 1 to 5 to the matrix. They should also try to find the economical and social impacts during the whole process. As for the example of plastic, they can briefly understand that plastic is made of petroleum and it will create a lot of CO2 and green house gas during the production process. In this process, although the economic benefit is high, it affects the environment because of the exploitation of the land and natural resources, and creates pollutions in many aspects. It also has great impacts to the environment at the end of life stage and many people are affected by it.

After they have completed the matrix, they can figure out which parts are most problematic or which parts they want to improve. The matrix can also help to analyse and compare with alternative materials or ways of production, which assist the designers to identify new design opportunities. The tool has been proved to be simple to use and effectively helped the students to identify design opportunities.

In the next section, I will demonstrate two student projects which have used these tools to develop the Circular Economy design.

3. EXAMPLES OF DESIGN FOR CIRCULAR ECONOMY

This section illustrates two student projects using the above mentioned process and tools. The six student groups tried to tackle the most pressing environmental problems in China, including baby toys and furniture, take-out table-wares, online shopping boxes, food waste, as well as fashion clothes. Two projects were selected to illustrate in this paper, they include: Redesign the baby beds and Take-out lunch boxes. The students needed to use a PSSD approach including to design a sustainability product with a system. Rather than focused on the products, they were encouraged to focus on the user needs since it can help to rethink a radical innovative solutions beyond just improving the existing product and system.

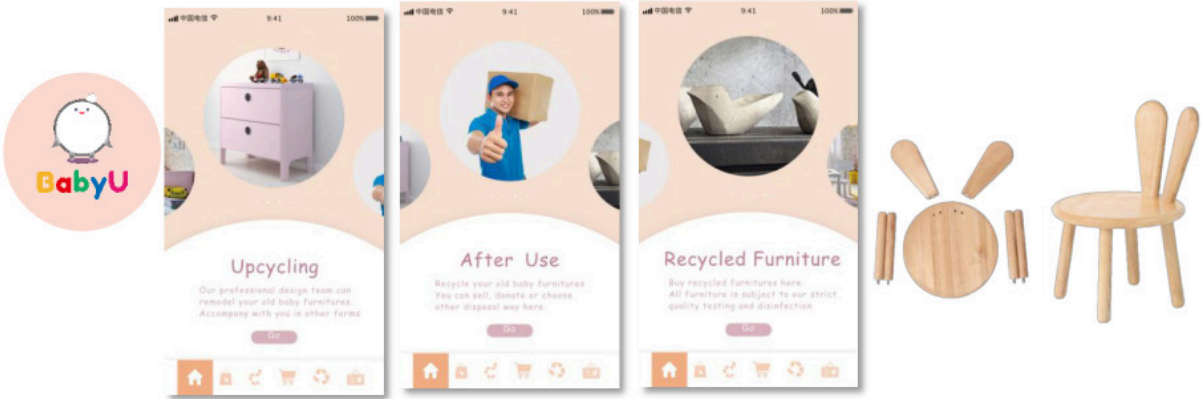
3.1. Baby beds

The group of students started by doing some research and interviews of families who have a little child. They found that baby furniture is a big problem for many families when their child grows up. Some of them would give it to their relatives or friends, but most of them just discarded them. The user needs include: provide easier ways to sell and recycle their useless furniture; a more secure platform to buy second-hand children's goods; the furniture which can be kept to be functional longer with their children.

According to the finding, their goal was to extend the life span of the baby beds. They initially just focused on redesigning the baby beds and found that numerous baby bed designs have tackled this problems in the market. The idea was also not good enough to provide a sustainable solution.

By rethinking the questions "Where does the material come from?" and "How the product is made, sold and used?", they conducted research about the product life cycle from raw material sources, pre-production, production, delivery, use and end of life. After they collected the information, they analyzed the information by using the Sustainable Product Matrix. They found that several areas were particularly problematic including the preproduction, production, and end of life. For instance, in preproduction, a large amount of trees are cut down in order to produce the timbers for the furniture which has impacts on the ecological system. In production, it creates plenty of dusts and wastes, which affects the health for the workers and carpenters who are working in the furniture factories. In the delivery and transportation, a lot of energy is used and plenty of carbon dioxide is generated. Finally, if the baby beds are discarded in the landfills, they will create many environmental problems. After this analysis, they realized that if they only redesign the baby beds, it can merely solve a few parts of the environmental problems.

The introduction of System map and Stakeholder map helped them to understand the interrelationships among the stakeholders in the complex system. They found that many stakeholders and processes are involved in the system which require the use of a large amount of energy and resources. After brainstorming and rethinking the production and consumption process, as well as the stakeholders, they came up with an idea of building a platform "Baby U" to line up with the local factories and consumers (Figure 1). The factories can sell the baby beds directly to the consumers. When the baby bed is no longer useful for the consumers, they can trade it back to the factories for repairing or upcycling into baby furniture, or they can sell it to the other consumers if the baby bed is in good condition. In this business model, the local factories can gain loyal customers, on the other hand, the customers can obtain personalized services and save money. Since the materials and products are from the local region, it reduces the intermediates and also saves energy in transportation. The idea achieves a win-win solution that is beneficial to the factories, customers and the environment. The sustainable development goals of economic, environmental, and social gain can be accomplished.



[Figure 1] Baby Furniture Sustainable System (Mobile application and dissembled furniture made of recycled baby beds)

3.2. Take-out lunch boxes

Take-out food is very popular in China. It's particularly popular for college students since they are very busy in their study and they seek a most convenient way to eat. However, when take-out food brings a lot of convenient, it also generates serious environmental problems since most of the table-wares are made by plastic and they are usually just discarded after used. So this group of students focused on reducing the use of plastic table-wares of take-out food for college students.

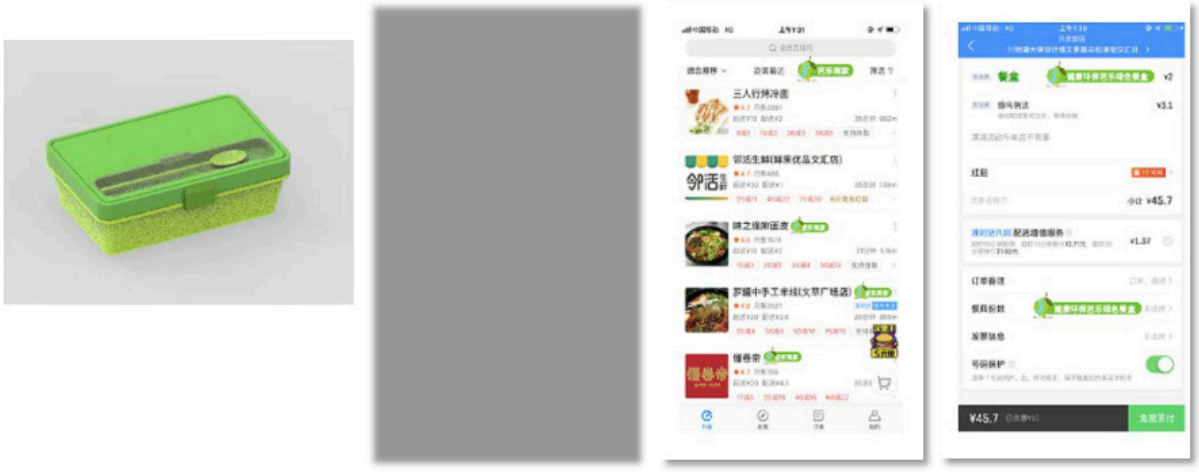
They found from their research that the user needs in this case was convenient, clean, healthy, and environmentally friendly. Although many university students are aware of the problem, they have no choice since it is a very convenient way for them and they do not know how to deal with this problem.

Similar to the previous group, they started by focusing on only redesigning the table-wares. They initially proposed to use biodegradable materials such as wheat for the new designed lunch boxes and table-wares. However, when considering if using wheat for the lunch boxes, it would detriment to the food system. Moreover, if the wheat lunchboxes are finally discarded in the landfill, it will not reduce the harm on the environment.

After using the Sustainable Product Matrix, they started to comprehend the complexity of the existing system and how impacts the material will be in the whole product life cycle. They came up with an idea to develop a recycling take-out tableware system called "Guava Plant" which included a non-profit company, a big online take-out food platform and the local restaurants. They designed a new lunch boxes and table-wares made of Polypropylene(PP), a white, mechanically rugged material and has a high chemical resistance, which can be used for thousands of times. The non-profit company sells the new lunch boxes to the restaurants and collects the used lunch boxes. After collecting the lunch boxes, they use sodium bicarbonate, which is a wide variety of household use material, for cleaning the table-wares, then sterilize them and deliver them to the restaurants to use again. Sodium bicarbonate has good effect on cleaning and diminishing odors, and it is considered to have low environmental impacts (HERA, 2005) The leftover food will be processed for manuring plants or feeding pigs. Moreover, the company will employ people to clean the table-wares which will create jobs in the new system.

To provide incentives, the colleges students pay deposits for the table wares and gain points by recycling the table wares. For the restaurants and the online food delivery platform, the environmental friendly practice can create corporate good will and better promote their businesses. In order to promote their environmental mission, the non-profit company can also provide company tours for the public. The company activities and environmental information is also provided on the company's website and WeChat official account to promote the environmental message to the public and their customers (Figure 2). In this case, the new solution also provides mutual benefits for different stakeholders and the environment.

Both examples demonstrated that the students developed a more holistic design thinking of the product/system by deeper and thorough understanding the whole life cycle of a product from the raw materials to its end of life. Their design concepts include the considerations of the sources of raw materials, production process, delivery, consumption, use and discard. Through this project, the students learned to search for alternative materials and rethink the existing production and consumption processes that are problematic.



[Figure 2] Take-Out Food Tableware Recycle System (Lunchbox and Online Food Delivery Platform)

4. DISCUSSION AND CONCLUSION

In this paper, I have described how I used Circular Design and Life cycle thinking in teaching a Design for Sustainability module. In the design process, I argue that 'Exploration' is an important part in Sustainability design as well as for Design for Circular Economy since designers need to consider different aspects and trade-off the less favorable options by analysing different alternatives to make better decisions. The exploration process also helps designers in creating new solutions. In this process, designers have to gain sufficient knowledge and information due to the

complexity of the materials, practices and the system in a product life cycle. Therefore a tool "Sustainable Product Matrix" was developed to help students gain better understanding and insights.

The Sustainable Product Matrix is attempted to guide designers to develop a life cycle thinking and provides a comprehensive tool for them to research and analyse the existing system of a product life cycle. It helps students to see the problems clearly in the process and identify the areas they want to solve. The matrix can also help to find a better solutions by comparing different materials and ways of making, delivering, using and discarding. By using the tool, the students learned to think about the origin of the materials and how a design can have impacts on the environment, economy, and society in the whole product life cycle.

They also learned to think in a system and understand their design has impacts on many stakeholders and the environment. As one student wrote in his reflection of the online delivery box project:

"I learned how to get deeper understanding about one product. Because one product can have many users and stakeholders in its life-circle. So designers should consider each aspect to make a design. Even an express box, when design it, designers should think about the workers, collectors and paper mill workers. Because each of them has different duties, so if designers can think more, the workers can be more convenient to package the boxes, the collectors will make more money, the paper mill workers will save more time and energy to recycle these boxes. Also, the environment will be better, the trees will be more."

So the design methods guided them to think more holistically in their design, including the stakeholders and how the new design could provide benefits to all the stakeholders involved, not only the users.

The tool is new and it has some disadvantages, for example it does not help designers to analyse very detailed and technical information such as how many materials and energy they need to produce a plastic bag, or how much they damage the environment or how much economic gain or loss in the process. However, the tool is intended to guide the designers to research and understand the relationships of each aspects in the product life cycle, so it aimed to make it simple and easy to use. The matrix, although not very detailed, provide deeper insights for designers to reflect and rethink the existing process and make better and innovative decisions. The above projects have showed that the tool has effectively achieved the purposes.

During the design process, some shortcomings and hurdles were identified for Design for Circular Economy. First of all, CE cannot be successful without changing the consumers' attitudes, behaviours, and the way of consumption. For example, the reused or exchange of baby beds concept would encounter barriers if the consumers' perception of using this service is negative. As Korhonen et al (2018, p.43) state, "If the current consumption culture will not change, CE will remain as a technical tool that does not change the course of the current unsustainable economic paradigm."

The CE concept is mainly focused on the production side rather than from the users' needs and perspectives which only created process innovation sometimes. Hence, in the student projects, students were encouraged to focus on the user needs and rethink a new way to satisfy the needs. For example, parents just want to buy a good and safe baby bed for their baby, and they would like to handle it when the child grows up. So the material, in this case is wood, does not need a completely new one. To focus on user needs and rethink the process, the students come up with an idea of working with local factories and recycling the baby beds after used. By working with the local factories and involving the customers in the process, they can tailor their own needs for the baby beds and they know where and how the beds are made and recycled, which can reduce their uncertainty. Therefore, focusing on users needs, providing values, as well as promoting behaviour change could help to develop radical innovation for system change.

Secondly, CE proposes to use renewable energy to develop a design. It is a good vision and should be pursued. However, in reality, the technologies of the renewable energy are still not very efficient and too expensive to use. It

lacks the motivation of product manufacturers as well as consumers to adopt the technologies. Moreover, using renewable energy technologies, such as solar energy or wind energy, requires special technical supports and a multidisciplinary team is necessary to make the design concept feasible.

Thirdly, CE is complex for its interdependencies of materials, energy flows, and activities. As Korhonen et al (2018) identifies there are six limitations and challenges in the concept of CE regarding environmental sustainability alone, such as thermodynamics, definition of CE system boundaries, management of the CE-type interorganizational and inter-sectoral material and energy flows, even social and cultural issues of waste and waste management. Many corporations still reluctance to adopt new modes of practice due to the risks and uncertainty. Nevertheless, several examples from around the world have implemented circular business models and showed to be successful to some extent (Guldmann, 2018; Valavanidis, 2019).

CE is one of the promising solutions for sustainable future but the road to completely achieve it is long. Design for Circular Economy is still in its infancy and the approach, tools and methods will surely be developed and evolved in the coming future. The design process and projects shared in this paper are just a first attempt to introduce the CE concept to design students and the tools and methods still need to be enhanced in the future. But it has showed that the methods it used has effectively helped designers to gain deeper insights of the sutainability problems and redesign more innovative and comprehensive solutions.

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