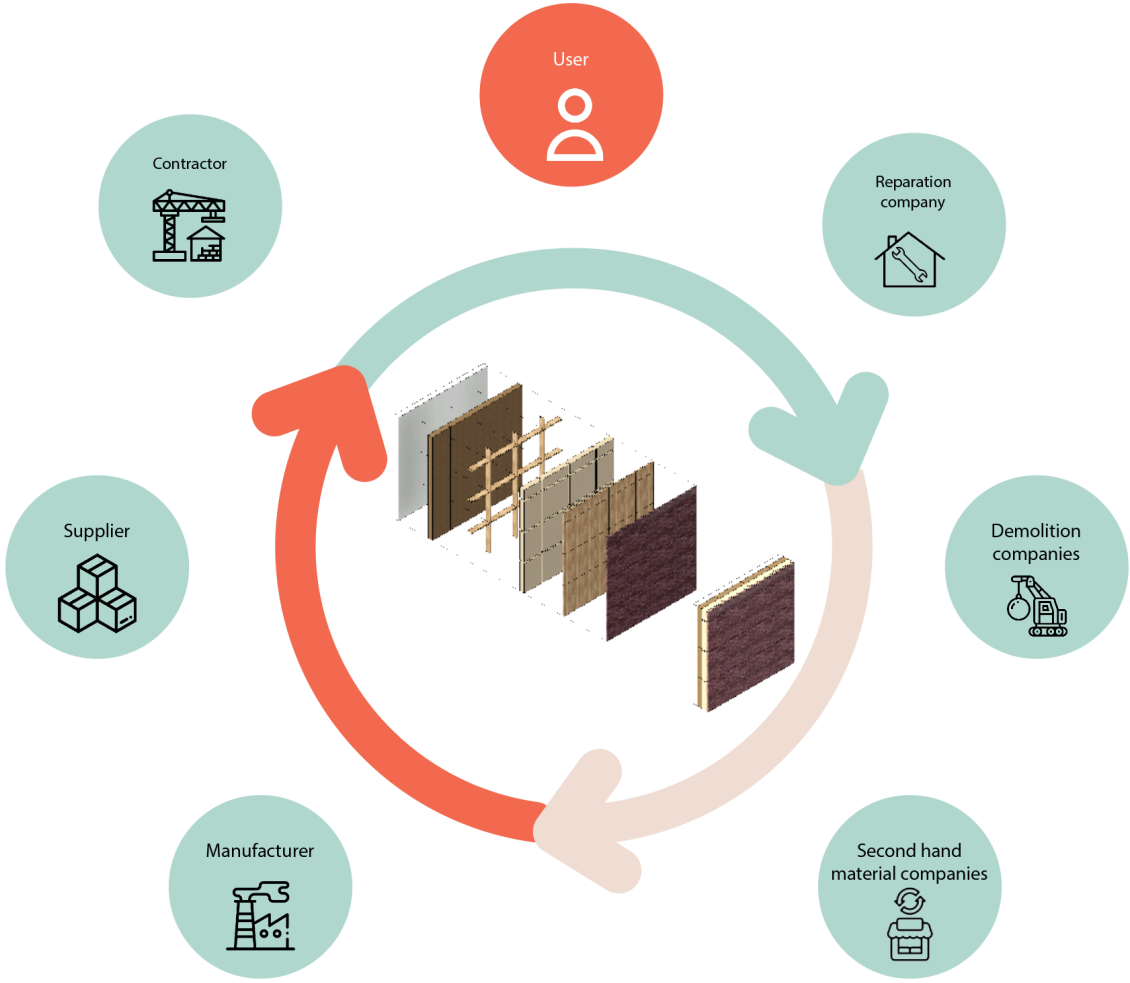


Circular Skin: Circular supply chains for housing renovation

Master thesis project

by Andrei Saceanu

Master Thesis Project
Construction Management and Engineering
Delft University of Technology

Circular Skin: Circular supply chain for housing renovation by

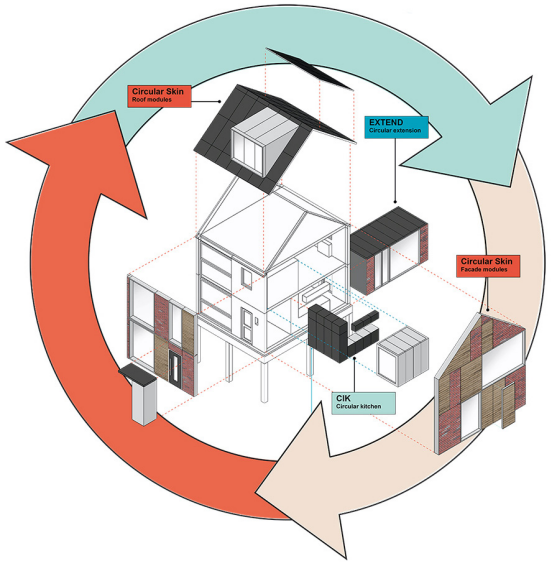
Andrei Saceanu
4914104

Under Supervision of:

Prof. Dr. Paul W Chan
Lr. Anne van Stijn
Associate Professor Gerard van Bortel

2020-2021

TU Delft Delft University of Technology



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Acknowledgement: Big thanks to...

I cannot express enough gratitude to my committee for their continued support and encouragement: Paul, Anne and Gerrard. I offer my real appreciation for the incredible pieces of advice, availability, explicative mails, patience, promptness and friendliness. One day, I want to shake your hands and thank you in person.

The purpose of this research could not have been accomplished without the support of my fellow CME's: Denis and Stefanos.

I want to thank especially to my caring family who understood and supported me. I will never forget the days when they were saying: you started on this path, you have to go till the end. Vă mulțumesc și vă iubesc!

I want to thank my friends: Andrei, Maaz, Pedro, Morgana, Sam, Blanca, Stefan and Vlad for spending this quarantine together next to each other or virtually.

Finally, Alejandra: my deepest gratitude. Your help when the times got rough is much valued and noted. My heartfelt appreciations.

Without any of these marvellous people, this graduation work would not have been the same.

Thank you! Dankjewel! Mulțumesc!

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And the adventure begins...

I. Introduction

Over the last years, humanity has realised that the current ways of production, distribution and consumption are putting an enormous burden on our planet

Experts forecast that the world population will continue to grow in the future, reaching 9 billion by 2050. The population growth will determine a higher demand for resources, causing scarcity in the environment. (Bastein, 2013).

The economy and society are in continuous development. Yet, the linear model of the supply chain remains greatly unchanged since the industrial revolution in the 18th century. The built environment is responsible for 40% of the waste production, 50% of raw materials consumption, 40% of the total energy use (Schoolderman et al., 2014). Furthermore, the existing buildings produce 36% of the CO2 emissions in the European Union (European Commission, 2008, European Commission, 2014) and also the built environment represents the most significant industry with 38% of the total energy consumption, followed by the transport sector (European Commission, 2016a). Specifically, the construction industry is one of the most conservative sectors based on a linear model that embraces a make-take-dispose consumption system. The traditional "take-make-dispose" represents an economic-end and a continuous generator of waste. (EMF, 2013) The alternative is implementing a circular supply chain.

One of the most efficient ways to reduce energy consumption is to insulate the entire exterior of the house, including walls and roof, which has proven to be economically viable for areas with cold winters and significant heating requirements, like the Netherlands (Lucero-Álvarez et al., 2016). In the Netherlands, a high number of dwellings require more energy-efficient insulation. In this renovation process, the materials used ought to be chosen wisely, not to cause harm to the environment.
TU Delft, alongside AMS Institute, Ymere and Dura Vermeer is working on creating a Circular Skin for the energy retrofitting of Dutch houses.
After several tests, the TU Delft Circular Skin proved that technically it is possible to integrate the circularity into facade renovation skin. Circular Skin enhances circular solutions like recycling, repair, refurbishment or reusing the components of the product that will determine a decrease of the raw materials consumption and energy expenditure. (EMF, 2015) Even though the technical design of the Circular Skin was proved to be circular, its integration in a circular supply chain is still uncertain.

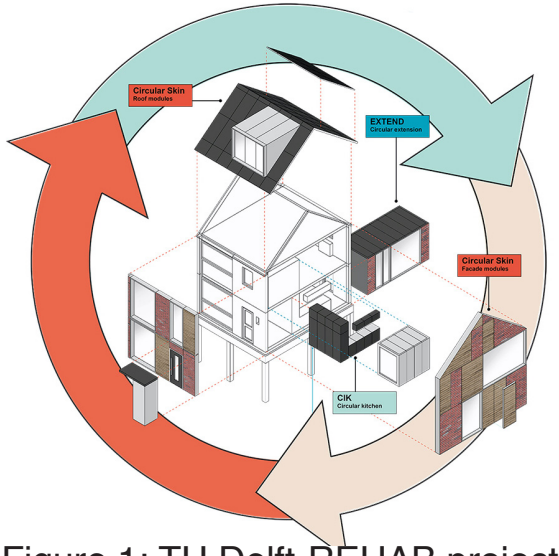

Figure 1: TU Delft-REHAB project
Source: Van Stijn, 2020

II. Problem description

The TU Delft REHAB team proved, from the technical point of view, it is possible to integrate circularity into the insulation facade. The Circular Skin design is modular (Plug and Play) based on easy to dis/re-assemble parts containing reclaimed, bio-based and non-virgin materials. A Plug and Play facade can be partially or completely disassembled because it is designed to be adaptable and flexible to the user's needs. The modularity aspect will substantially impact the supply chain because a specific party should assume the responsibility for the product installation, disassembling and return. The Circular Skin design is undoubtedly circular, but it is questionable if the whole product can be integrated into a circular supply chain.

The general concepts of circular economy and circular supply chains have already been researched widely, and even there are few examples of circular supply chains presented in the literature. Unfortunately, there is a gap in the research area regarding the possibilities and limitations of implementing precisely the Circular Skin components into a circular supply chain. There are many possible solutions to create a circular supply chain, but for the moment, there is a shortage of analysis in the supply chain area. Such analysis should include: a decision regarding the main actor (manufacturer, contractor or the user), open/close loop, open/close source, the return flow and the remanufacturing process.

Furthermore, the literature so far has not presented any possible variants for a circular supply chain in the area of housing renovation. The design of a product could be circular, but if the product could not be integrated into a circular supply chain, the circularity principle is invalid. Therefore, the purpose of this graduation report is to analyse the stakeholders' possibilities of integrating Circular Skin in a circular supply chain.

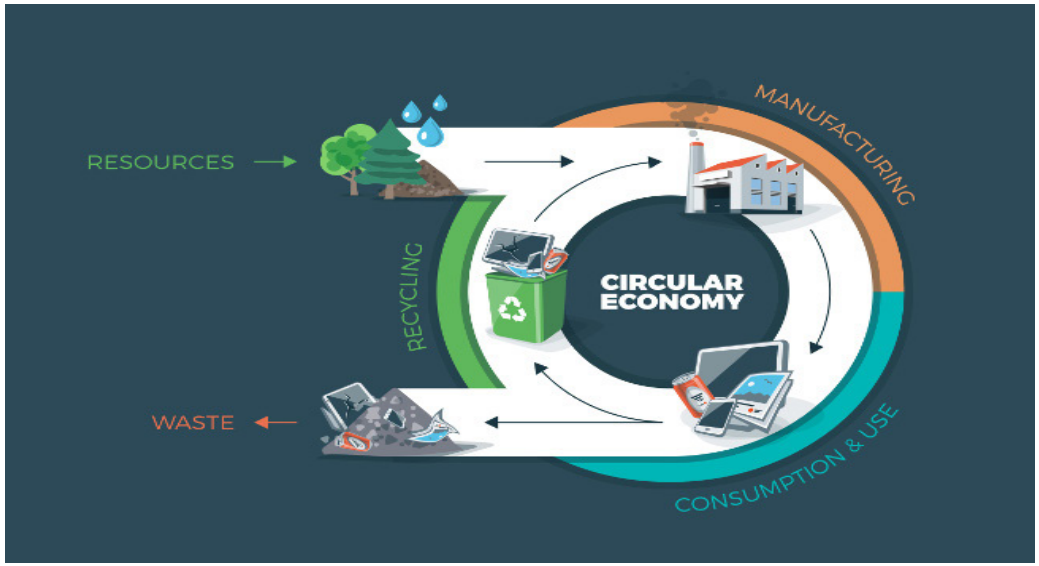

Figure 2: Example of a circular supply chain
Source: Staff, 2020

III. Research

1 Research questions

This study aims to determine the possibilities and limitations of stakeholders in implementing the Circular Skin created by TU Delft in the circular supply chains, constituting the main question. This report will propose new models of circular supply chain and analyse the feasibility of the circular supply chains in the housing renovation sector. Alongside the economic concerns about the transition to circularity, the research will discuss resource efficiency and the environmental impact of every measure.

For a thoughtful analysis, several stakeholders will be interviewed, who are involved in the exchange process between supply and demand sides from the industry. During the interviews, possibilities and limitations for implementing circularity will be identified, and possible variants of the circular supply chain will be analysed.

Main question:

Which are the possibilities and limitations of stakeholders involved in the REHAB project in implementing the Circular Skin in a circular supply chain?

Secondary questions:

1) How does the current linear supply chain work in the construction industry?
2) Which are possible models of a circular supply chain that currently exist in the built environment?
3) Which are the possible variants of circular supply chains suitable for the Circular Skin developed by TU Delft?
4) Is this transition to the new variants of circular supply chains environmental friendly, resource-efficient and economically feasible for the housing facade renovation using Circular Skin developed by TU Delft?

The sub-questions follow a line of argumentation to understand the proper steps of implementing the Circular Skin in a circular supply chain.

The first subquestion helps to understand better the current linear supply chain in the construction industry. Two elements are very crucial: the consumption of resources and the production of waste.

The second sub-question prepares the creation of the new variants of the circular supply chain for Circular Skin by analysing the existing circular supply chain presented in the literature and extracting which features could be used for Circular Skin.

The third sub-questions represents the synthesis phase and asks for identifying specific variants of circular supply chains. The circular variants will be helpful to discover distinct possibilities and limitations for particular supply chains, avoiding a monotonous generalisation.

The last sub-question is designed for assisting the reader in understanding the characteristics of each variant in terms of environment, resources and economic feasibility.

Research strategy

The scientific inquiry of this graduation report will use the guidance of Research through design (RtD) methodology, using the resources of the unique perspectives obtained through design methods. Research through design is formed of four phases: analysis, synthesis, simulation and evaluation.

Firstly, the analysis is based on a literature review to determine the existing knowledge on the circular economy, possibilities and limitations of stakeholders and existing circular supply chain models.

The literature review is vital for this report because it is necessary to determine what was studied until the present moment. Besides that, the literature review is essential to understand the concept of circularity, find examples of circular supply chains, and discover possibilities and limitations of different circular project implementation processes.

Figure 3; Research strategy
Drawing by the author

Secondly, the synthesis phase aims to determine possible variants of the circular supply chain for the Circular Skin. The design of the variants is based significantly on the literature review, starting from what we already now and reaching for an innovative idea. This phase includes a charette day, an intense design activity, to kick-start the generation of design variants for integrating Circular Skin into a circular supply skin.

Furthermore, the simulation phase is based on semi-structured interviews with stakeholders involved in the Rehab Project that are supporting the creation of the Circular Skin. The interviews are meant to provide data for identifying the interests of stakeholders, their view over the circular economy and the possibilities of transition from linear to circular supply chains. The interviewees will rate the variants based on three fundamental criteria: environmental impact, resource efficiency and economic feasibility.

Finally, the evaluation phase will examine the stakeholders' answer compared to the literature results. Furthermore, the evaluation will present the possibilities and limitations for each variant individually, avoiding unclarities. Probably, different relations between the interviewee's answer and the literature topics will generate unpredictable conclusions.

In conclusion, these graduation research results serve as the implementation possibilities and limitations for the Circular Skin in a circular supply chain. Additionally, the researcher will present several possible variants of circular supply chains that resulted from the conceptual design and the stakeholders' input. Every alternative of circular supply chain will be evaluated, presenting the advantages and disadvantages according to three criteria: environmental friendly, resource efficiency and economic feasibility.

For example, one of the interview questions will be related to cost-saving from using renewable materials. CE drives sustainable consumption and steers public and private investment, eventually leading to economic growth (Tseng et al., 2019). Currently, research and practices in CE emphasise that, if manufacturing sectors practice recycling and realise material cost savings, it can stimulate economic activities through eco-product development, remanufacturing, and refurbishment. Furthermore, it can be discussed which governmental measures are necessary to encourage private operators to recycle or rejuvenate the construction materials. A possible solution can be that the government should impose limitations on what products can go to waste, what products must be reclaimed, how much the given entity may use raw materials, and what processes are required for supply chain entities who have stepped out of the traditional product-sale relationship. Nevertheless, consumers stand out as the vital driving force behind the circular supply chain.

IV. Theoretical background

The theoretical background is the chapter that can introduce and discuss theories or concepts, which will be used in the research study. For a better understanding of the research, the theoretical contains the following concepts:

- Circular economy in the global context,
- Circular Supply Chain,
- Ellen MacArthur's Butterfly model,
- Slowing, closing and narrowing
- Open vs Closed-loop supply chain
- Open vs Closed source
- The Circular Skin by TU Delft

1. Circular economy in the global context

Nowadays, the current linear economic model: take-make-dispose is leading to scarcity of raw materials, the volatility of resources and increased prices for the manufacturing industry (EMF, 2013). The primary challenges on the planetary resources are generated by two main factors: the growth of the world population and the prosperity of people due to the economic growth (Swilling, 2011).

The built environment is responsible for 40% of the waste production, 50% of raw material consumption and 40% of the total energy use (Schoolderman et al., 2014).

Circular economy (CE) represents an alternative to the current linear economic model. A list of design strategies was created to facilitate the transition from linear to the circular economy: slowing resource loops, closing resource loops and narrowing resource flows. (Bocken et al., 2016)

The circular supply chains allow the industry to recycle/repair/refurbish/ reuse the products and to re-include them in the supply chain. According to the Ellen MacArthur Foundation, if the general principles of the circular economy will be applied universally, the consumption of primary materials in the European Union would register a significant decrease in the construction sector by 32% by 2030 and 53% by 2050. (EMF, 2015)

2. What is the Circular Supply Chain?

At its core, the circular supply chain replaces the linear model with the model "make, use, restore/ regenerate". Circular economy implies the systematical restoration of the used materials, products and their reintegration in the cycle.

Nonetheless, the precise definition of the circular supply chain is not yet known, but the vast majority of the scientific community considers it to be the sustainable alternative to a linear supply model. (Farooque et al., 2019) It is considered that the circular supply chain is achieved by the integration of natural ecosystems and the industrial process. The zero-waste vision is an essential aspect of the circularity: the technical components are remanufactured and reused, and

the biological nutrients regenerate in the natural cycles. (Farooque et al., 2019)

Implementing a circular supply chain at the micro-level will determine a change in design, enabling materials at the end of their lifecycle to be re-introduced in the supply chain through rejuvenating, remanufacturing or recycling process. (Nasir et al., 2016)

3. Ellen MacArthur's Butterfly model

The Ellen MacArthur Foundation developed a framework that depicts the lifecycle of the technical (blue loop) and biotic nutrients (green loop). The Butterfly Model presents the advantages of a circular economy: maximising the usability of products and raw materials and minimising the waste. (EMF, 2015)

The EMF underlines the idea that circularity is achieved as long as the components are completing the tightest circles possible for

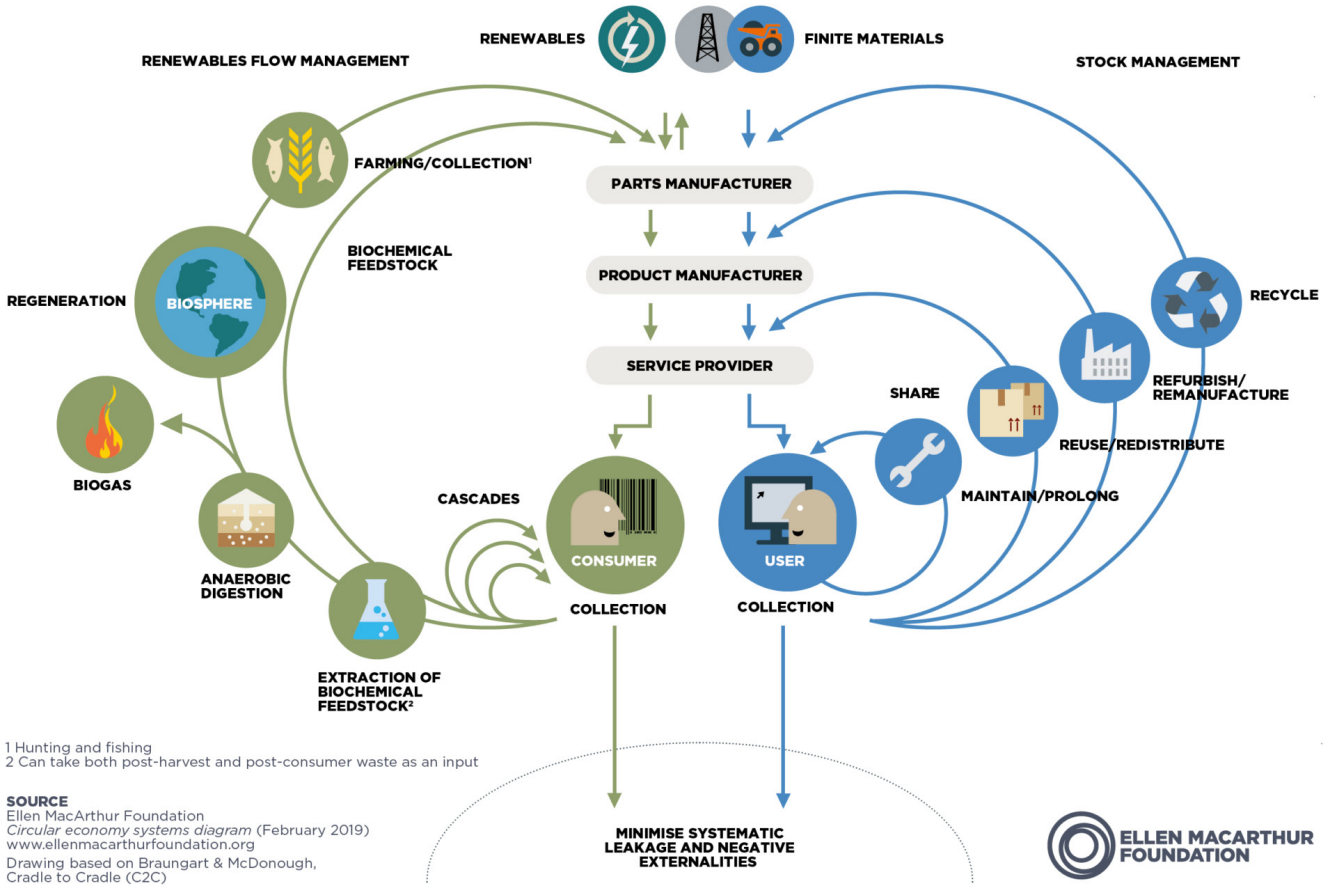

Figure 4: Ellen MacArthur's Butterfly model
Source: EMF, 2013

the most extended period to limit the consumption of energy, manufacturing and transportation. (Bastein et al. 2013)

The butterfly model distinguishes between two spheres: biological cycles and technical cycles.
The biological cycles present the natural cycles of consuming the bio-degradable materials. The biological nutrients such as food, wooden components and textiles after their use, could be re-incorporated by consumption in the eco-system, regenerated and be consumed again and again. (EMF, 2013) .

Furthermore, the biological cycles are represented by cascades, where the components are cyclically used for different functions according to their applicability. For example, the flesh of the orange is eaten, and special chemicals are extracted from orange peels. (EMF, 2015)

On the other hand, in the circular economic model, the technical nutrients are not consumed or landfilled but maintained, reused, refurbished and in the last option, recycled. The technical products contain components and materials, which are not bio-degradable in time, like most plastics and metals. (EMF, 2013) The technical nutrients should be contained in the tightest loop for the maximum time possible to minimize the use of the planet's resources.

4. Slowing, closing and narrowing

Bocken distinguished three possible strategies that can be applied for the implementation of the circular economy: slowing resource loops, closing resource loops and narrowing resource flows. (Bocken et al., 2016)

Following Bocken, the biological and technical nutrients' cycles (EMF, 2013) can be closed, narrowed, or slowed for limiting resource consumption, reducing waste and enhancing sustainability performance.

Firstly, the most common idea for limiting environmental harm is to narrow the resources by efficiency improvements like material reduction and energy savings. Moreover, slowing is a complementary strategy for narrowing. Slowing resource loops could be achieved by extending the life of the product.

Finally, the last strategy, closing the loops, is based on re-integrating the component into a new lifecycle by re-assembly or recycling measures.

Anne van Stijn, my thesis supervisor, used Bocken's theory to produce a framework for describing the design strategies for slowing closing and narrowing resource flows.

Figure 5: Slowing, closing and narrowing framework
Source: van Stijn, 2020

5. Open vs Closed loop supply chain

In the last decades, the sustainable supply chain solutions have represented a priority for the business and governmental sectors. There is a universal consensus among all key stakeholders on the climate action that encompasses reducing the inequality, decreasing the resource scarcity and limiting the waste. (SustainAbility, 2016).

The return and readjustment of a product could be made by disassembling, reuse, recycling and refurbishing. The difference between the open and closed-loop supply chain influences the logistical operation in return process. The closed-loop implies the return to the original manufacturer, and usually, the manufacturer collects the used product. (Özceylan, 2016).

The closed-loop supply chain allows the return of the products to the original supplier or producer, while the open-loop concedes the return

also to other parties interested in reusing the components. (Özceylan, 2016) The closed-loop supply chain reintroduces the product in the same loop, after return, the initial producer being responsible for the return. (Guide et al., 2003) The manufacturer, in the closed-loop supply chain, is physically and economically responsible for the whole lifecycle of the product, including the end-life. (Bufardi, et al., 2004)

In the closed-loop supply chain, the producer integrates design, control, operation and return in the same loop, having the purpose of maximising the lifespan of products by recovering, remanufacturing and reintegrate them in the lifecycle. (Guide and Van Wassenhove, 2006)

The closed-loop supply chain represents the practical application of ideal zero-waste supply chain because the return will become a main influence factor for the product design. (Cecere, 2016) One of the challenges for many companies is represented by the recovery activities of products, neglecting in this way, the potential of creation that could be generated by other parties. (Atasu et al., 2008)

On the other side, the open-loop supply chain urges external parties to recover, remanufacture and reintegrate products outside the initial supply chain. (Gou et al., 2008) According to van Hoorn's results, the open-loop supply chain has the potential to become more environmentally friendly, resource-efficient and economically feasible as compared to the closed-loop if the business actors are financially incentivised. (van Hoorn,-)

Comparison	Open-loop	Closed-loop
Definition	Open-loop concedes the return also to other parties than the original manafacturer	The closed-loop supply chain allows the return of the products only to the original supplier or producer
Advantages	• Users Drive Choices • Freedom to innovate	• Ensures circularity • Cost savings for companies, which reused components
Disadvantages	• Circularity might be lost • Waste generated • Profit motive might affects the sustainability goals	• The logistic planning might be difficult for the return of the product • More bureaucracy in the companies: two extra departments return and transport
Examples	Television, furniture	Swapfiets bikes, Mitsubishi M-Use elevator
Circular Skin applicability	The components might be sold to different Second Hand broker	Circular Skin is returned to the original manufacturer; Leasing and Buyback

5. Open vs Closed source

In our new technological age, products could be divided according to their source in two distinctive categories: open source or closed source. The difference between these two systems is the possibility of modifying the characteristics of the product by the user (open source), while the close source model restricts the access of the user. The model of open/close source product is mostly used in the software industry. For example, Linux is an open-source operating system, while Windows is a close source system that does not allow the user to modify the source code. (Germonprez, 2012)

The close source product usually has a particular manual of instructions, and the user should follow that specific guideline. In case of a problem with the product, the product will be repaired only by the authorised service team.

Another particularity of the close source products is that the user cannot add, modify, replace or delete components of the product because these actions could determine voiding the warranty. The closed source model provides users with a specific solution. This solution could be helpful for the inexperienced client, who is not willing to spend much time deciding the most suitable solution. (Gaille, 2019) However, according to Pay, the complexity of close source merchandise will generate a higher price than the open-source ones. (Pay, 2015)

On the other hand, the open-source represents a collaborative model that has the potential to change the corporative culture of the organisations, increasing innovation and reducing costs. (Boehmke, 2017).

The benefits generated by the external input define the user as one of the stakeholders involved in the developmental process of products. (Morrison et al., 2000) An organisation that enhances the open-source supply chain will involve participative communities, creating collaboration and innovation. Innovation could include externalising the R&D, develop a new design of products, sharing the software code with other developers and more. (Boehmke, 2017).

6. The Circular Skin by TU Delft

A substantial number of buildings in Europe were built more than 50 years ago, and many dwellings in use are hundreds of years old (Economidou et al., 2011). In many cases, the old constructions consume a high amount of energy for operating and maintaining these buildings. The reduction of energy use is possible by efficient insulation, that will generate budget saving for the client and a limited environmental impact.

As a solution to the insulation challenge, TU Delft researchers initiated the research project REHAB to develop Circular Skin. Circular Skin is a facade covering, which improves the energy efficiency level of buildings in the Netherlands.

To better understand the Circular Skin's design and functionality, I performed two exploratory interviews with Henk Marsman and Bram van Vliet from the contractor Dura Vermeer and Bas Slager, a second-hand material specialist from Repurpose. The transcripts of the interviews are attached in Appendix A, respectively B. The primary objective of the exploratory interviews is to receive explanations and analyse the Circular Skin. Furthermore, the interview will approach the circular supply chain topic in the building renovation industry.

The particularity of the Circular Skin is represented by the development of circular building components for housing retrofits, which respects Bocken's strategies: decrease the usage of raw materials, extend the lifespan of components and close the resource loops.

Comparison	Open-source	Closed-source
Definition	Open-source gives the user the possibility to modify the characteristics of the product	The closed-loop restricts the access the access of the user
Advantages	• Flexibility to user needs and requirements • Increase innovation • Lower costs	• Authorised and experienced assistance • Safer and more practical for the user • Easier to control to product cycles, maintaining components at highest value
Disadvantages	• Unexperienced users might be vulnerable	• Higher costs • Inability to change the characteristics of the product
Examples	Linux	Microsoft Windows
Circular Skin applicability	The facade might be maintained or repaired by external contractor chosen by the user	The Circular Skin is maintained or repaired only by the manufacturer

The Circular Skin is developed according to the Butterfly model showed by Ellen MacArthur Foundation, which is a drive that presents the trajectory of the biological and technical nutrients. For both nutrients, there are several cascade applications from extractions through the economic system to re-introduction in the lifecycle (EMF, 2013).

TU Delft alongside AMS Institute, Ymere and Dura Vermeer designed the Circular Skin following the general lines of the circular economy: reducing the amount of material, maximising the usage of components and closing the resource loop.

Circular Skin should meet three essential parameters for respecting the circularity principle: product design, supply chain and business model. (Geissdoerfer et al., 2018). The incorporating process of the Circular Skin in the CE should be done from the incipient stage of the design because once specifications of the facade are established, only minor modifications can be done.

According to the principles enunciated above, the research developed five possible variants of Circular Skin, that will be tested afterwards:

- Variant 1: Using renewable and biodegradable materials;
- Variant 2: Using reused materials like solar panels, old Rockwool insulation and wooden slats;
- Variant 3: Using recycled materials;
- Variant 4: Using components that are easily diss- and re-assemble. In this way, the components could be reused.
- Variant 5: Modular facade, using LEGO blocks

Starting from these variants, 200 students have designed, constructed and tested a prototype of a “building block”, which is combining parts of roof, facade and floor. The results concluded that the Circular Skin should be a combination of the plug-and-play, reclaim and bio-skin variants. The main advantage of this PLUG and PLAY concept is the high frequency of replacing its components, which are mostly reusable or recyclable. The Circular SKIN could meet the user’s requirement, being flexible for different customisation. Another essential feature is that the house can be renovated, while the tenant still lives there.

The main components of the Circular Skin are:
Cavity filled with used insulation - Between the existing building and the new facade, it was created as a cavity, that will be filled with recycled or reused materials (recycled cellulose or wood fibre insulation). Using reused materials like old Rockwool insulation will generate circularity and will minimise the waste. The insulation can be procured from the demolition companies.

Timber frame structure - The main structure of the Circular Skin is based on a wooden timber frame with beams. The wood is a local product and has a low environmental impact. Furthermore, at the end of the product life, it could be disassembled and reused.

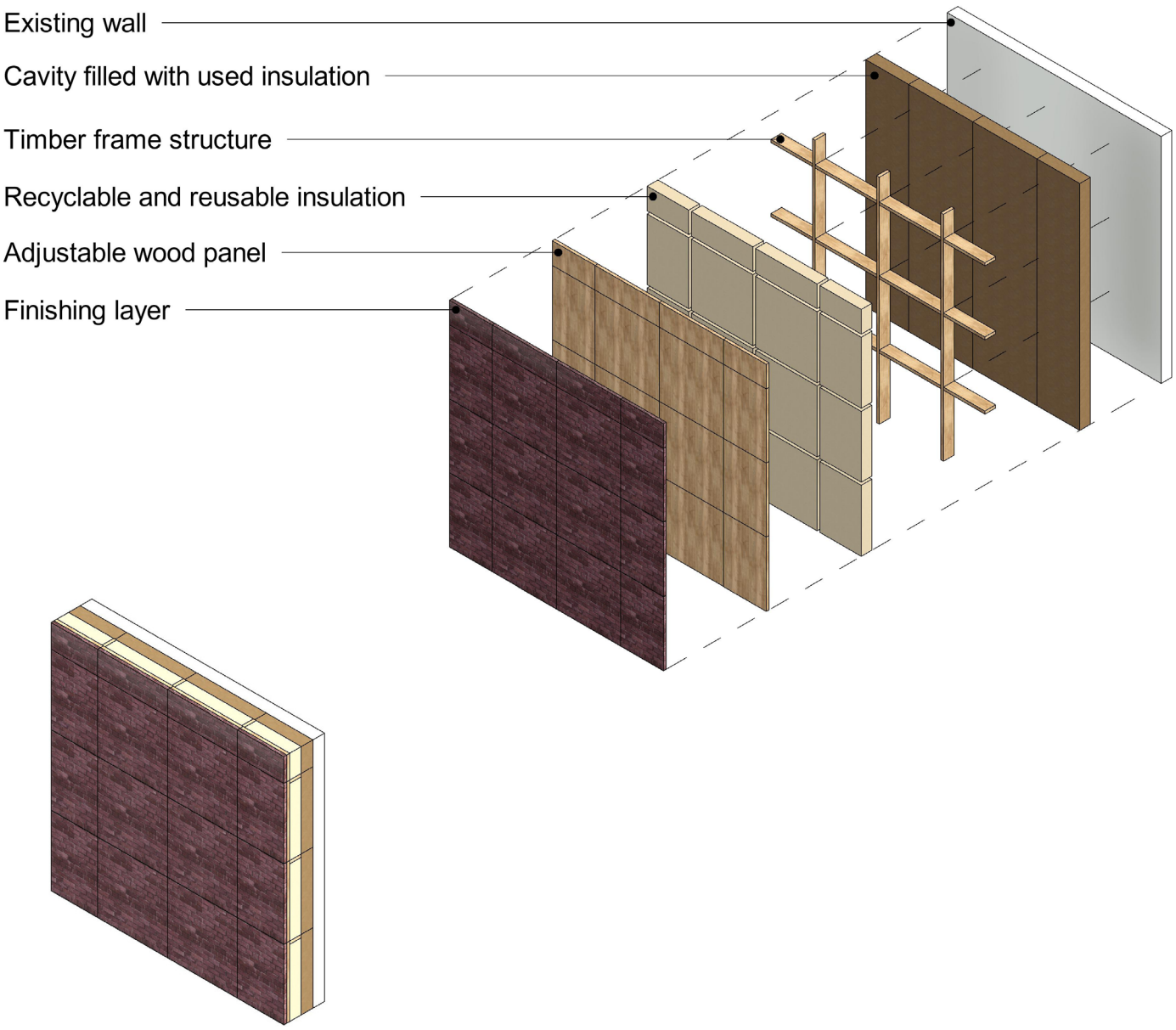

Figure 6: Circular Skin design
Drawing by the author

Insulation- The final solution has not been defined yet, but it is considered a reusable/recyclable material or a bio-based one. Depending on the final solution, the insulation should be circular and technical performant.

Adjustable wooden pannel - The facade is composed of standard dimension panels. Using Lego blocks was estimated to be too expensive, and the designers decided to use one panel that is adjustable and adaptable to different houses. The facade panels are a separate layer from the timber frame behind. They are hung up with a wooden rail system, and they are easy to click-on and off without having to remove the entire insulation timber frame. Moreover, the modularity is increasing the exchange, rapidity and adaptability for assembling the components.

The finishes- A meaningful discussion revolved around the brick panels, which is a very common exterior finishing in the Netherlands. Conventionally, the bricks solution is not circular, but the designers found a bricks producer, who can fix that.

V. The analysis

The analysis represents the foundation of the research because it is essential to discover and learn what was studied until the present moment. Without knowing what we already know, it is impossible to work to create something unique and innovative. The sub-questions regarding the current linear construction supply chain and the possible models of a circular supply chain will be addressed in the literature review to understand the present construction sector circumstances.

Furthermore, the research in this chapter focusses on determining the existing scientific knowledge about the possibilities and limitations for the stakeholders of the existing variants of the circular supply chain models in the building industry.

The literature has been gathered based on a Google Scholar search. The search was based on keywords presented in the list below.

Furthermore, using the references listed in the literature, other relevant articles were identified.

The research revealed numerous articles related mostly to the circular economy implementation. However, the scientific literature has not presented a high number of research papers of examples of the circular supply chain

The research revealed numerous articles related mostly to the circular economy implementation. However, the scientific literature has not presented a high number of research papers of examples of the circular supply chain.

Circular supply chain models:	**Possibilities and limitations stakeholders circular supply chain:**
• "Circular supply chain"	• "Circular supply chain"AND "stakeholders" AND (possibility* OR opportunity* OR enabler* OR strength*)
• "Circular supply chain" AND "(model* OR variant* OR design*)	• "Circular economy"AND "stakeholders" AND (possibility* OR opportunity* OR enabler* OR strength*)
• "Circular Economy" AND "Supply chain"	• "Circular supply chain"AND "stakeholders" AND (limitation* OR barrier* OR challenge* OR obstacle*)
• "Circular Economy" AND "Supply chain" AND (model* OR variant* OR design*)	• "Circular economy"AND "stakeholders" AND (limitation* OR barrier* OR challenge* OR obstacle*)

1. Current linear supply chain model in the construction sector

To be able to understand the concept of the circular supply chain in the built environment, we should first understand the current linear supply chain in the construction industry.

Nowadays, the construction industry is based generally on the linear supply chain, which creates an unfruitful loss of value at every lifecycle. (EMF, 2016). The final product generated by the construction activities is mostly designed for a single client. According to Serpell et al., the uniqueness and dynamics of the construction project lead to shortness of coordination, collaboration and engagement between contractors, suppliers, designers and clients. The design represents one of the principal vulnerabilities of the current linear supply chain because it does not present a proper solution for minimising waste.

(Serpell et al., 2014) The current linear system increases the scarcity

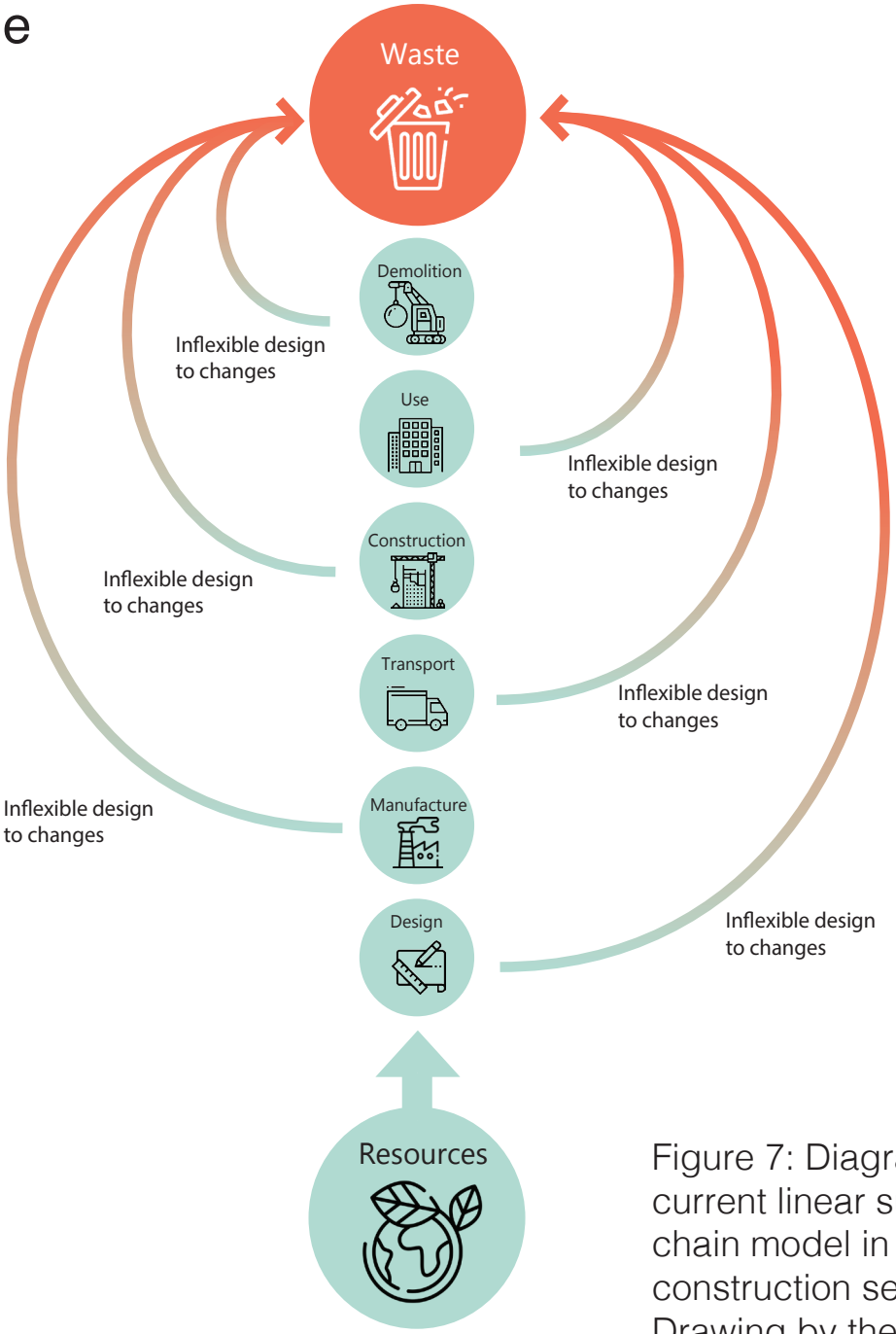

Figure 7: Diagram for current linear supply chain model in the construction sector Drawing by the author

of resources seeking to maintain economic growth. The waste resulted from the construction industry disturbs the natural eco-systems. (Meadows, 2004)

Ellen MacArthur Foundation examined alongside BAM and Arup the current linear supply chain in the building industry and presented several drawbacks of the actual state of the building sector:

- The design does not include a proper solution for minimizing waste
- The design is inflexible to possible changes according to the user's desire
- Components cannot be completely disassembled
- Components are constructed, manufactured and assembled on-site generating waste and residual materials
- The contractors often use new materials rather than used or recycled ones
- The As-built plans (for assembled elements) are not reflected in the maintenance or demolition phases
- An essential part of the components value is affected in the demolition phase because of disassembly limitations
- Defective waste separation jeopardizes the recycling process
- The return of building materials or components to the manufacturer is unmanageable (EMF, 2016)

Using the data presented by the Ellen Macarthur Foundation, a diagram was designed to simplify for the reader how the construction process consumes raw resources and causes waste.

In conclusion, the current linear supply chain presents multiple vulnerabilities because it does not present a precise solution for responsible consumption of resources or minimizing waste. For further steps of the research, it is important to understand the points enunciated by the Ellen MacArthur Foundation for preparing the supply chain variants for Circular Skin.

2. Existing circular supply chain models

For creating variants of circular supply chain for Circular Skin it is mandatory to study and learn which are the existing circular supply chain presented in the literature. In this subchapter, I will present six supply chain models suitable for my research, one describing a circular supply chain in construction sector and the rest of the five are describing the supply chain from the manufacturer's view.

2.1 Circular supply chain in building environment by Ellen MacArthur Foundation

Ellen MacArthur Foundation developed alongside BAM and Arup a new circular business model applicable for the construction sector. The contribution of all stakeholders involved is necessary to create a successful circular supply chain in order to get maximum value while avoiding any losses. (EMF, 2016).

A specific opportunity for manufacturers and suppliers is to recover materials and components at the end of their lifecycle, creating a possible resell, remanufacture, or recycle. Possessing ownership by the manufacturers affords long-term income, financial stability over price fluctuations and uninterrupted contact with clients. Manufacturers or suppliers or contractors retain the ownership of the product and deliver performance to the user, securing a constant income revenue.

The design should be included in the construction process from the preliminary phases to ensure flexibility, durability and deconstruction of the building product. The designers should operate in close collaboration with the manufacturers to guaranty that construction design could permit disassembly. Furthermore, the demolition phase could represent a source of materials from the built environment, minimising the waste.

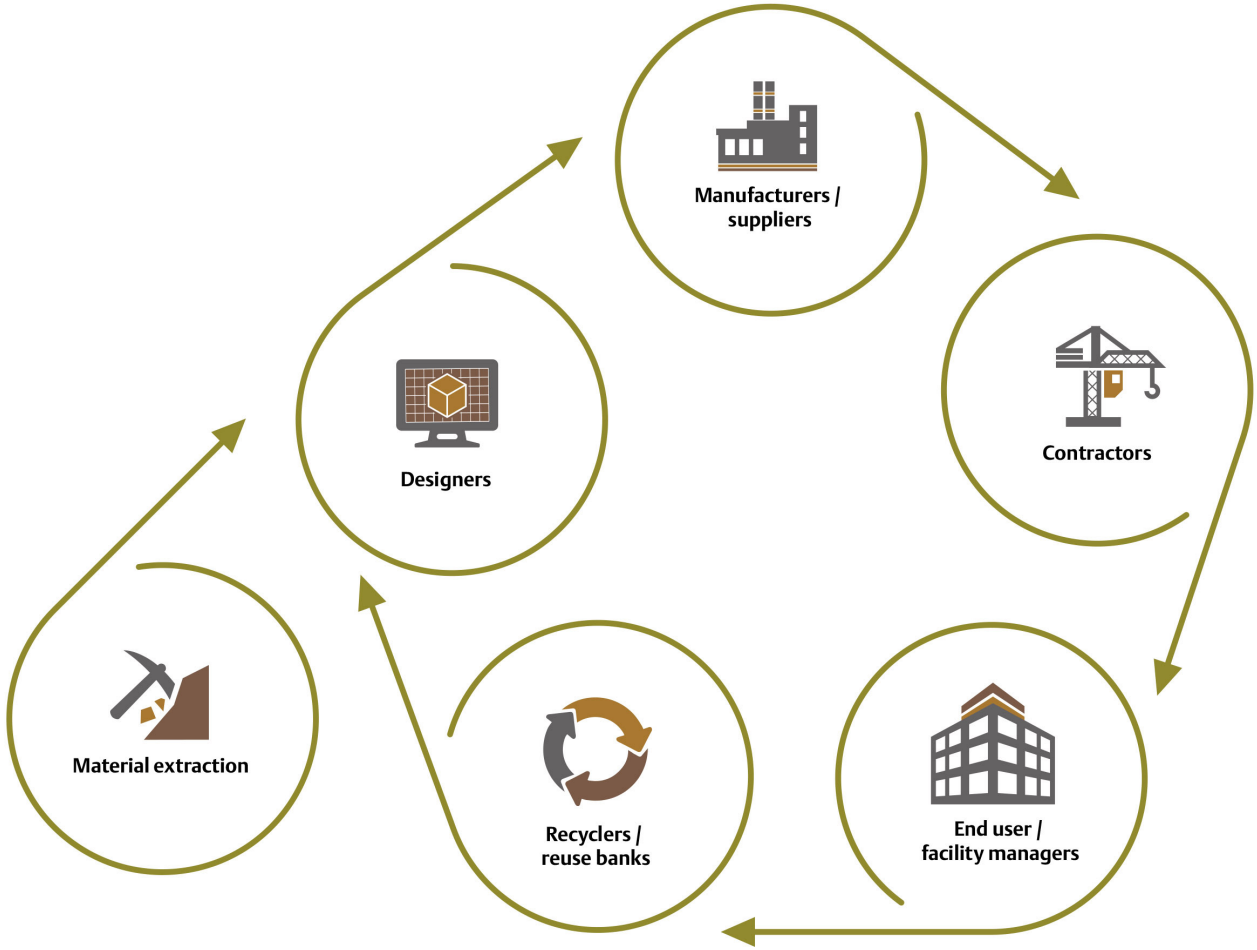

figure 8: Circular supply chain developed by Ellen MacArthur Foundation
source: EMF, 2016

Contractors should assume the responsibility to connect, discuss and find solutions with users, project owners and suppliers for implementing circular economy requirements in the construction project. Basically, a contractor is the main decision factor in the procurement and building processes, having the opportunity the ensure the usage of circular materials, components and techniques. (EMF, 2016)

Who?	Architect Structural engineer
What?	Should map and value circularity throughout the complete by generating functional solutions and expectedly innovation.
Why?	For ensuring durability, flexibility, reuse and deconstruction. Designers should discuss with the client possible reconfiguration by adopting a modular method (assemble/ disassemble of components)
Where?	For the whole construction process
When?	The implementation of design should be made in the earlier phases of the project

Who?	Manufacturers Suppliers
What?	Product passports might improve the transparency
Why?	It represents an opportunity to recover the component at the end of its lifespan. Products could be easily reused, recovered and recycled
Where?	Manufacturing industry
When?	From the extraction of the material until the construction site and possibly also in the demolition/ disassemble phase

Who?	Users
What?	Users could use inteligent lighting and HVAC systems
Why?	Maximise resident comfort and increase the operational efficiency of the building
Where?	For the whole construction process
When?	It should start with installation design phase

Who?	Contractors
What?	The contractor could choose to procure circular materials
Why?	To ensure circularity in the supply chain
Where?	For the whole construction process
When?	

Who?	Investors
What?	Might use circular criteria parameters to evaluate a project investment
Why?	To ensure circularity in the supply chain and gain a positive public perception
Where?	In the investment banking industry
When?	Investment phase

Who?	Demolition contractors
What?	Should expand their activity portfolio with disassembling activities and reuse material providing.
Why?	Reducing waste and creating a second income option by supplying reused material
Where?	Demolition industry
When?	At the end of building's lifespan

Who?	Developers
What?	Could use leasing models, moving their assets from CAPEX to OPEX
Why?	It frequently results in more fluid operational expenditure and significant tax deductions.
Where?	In the investment banking industry
When?	Investment phase

2.2 Circular supply chain by Manavalan

Another circular supply chain model was designed by Manavalan and Jayakrishna, incorporating the Cradle to Cradle principles and 6Rs policies to develop a synergetic system. Even if this circular supply chain is not related to the construction industry, it represents a good exemplification of the zero waste vision by using: remanufacture, reuse, recover, reduce, redesign and recover.

The circular example refers to a paper manufacturing organisation. The manufacturing process of finite products, papers, utilises renewable materials and eco-friendly technologies. The raw material, plant bagasse, is used to produce pulp. Following the process, the pulp is going through fermentation, boiling and bleaching. The residues from the fermentation of pulp are not wasted but supplied to the spirit industry. Furthermore, old paper obtained from recycling facilities is remanufactured through a boiling process. The steam resulted from the boiling process can be used to produce electricity for the factory, reducing energy consumption. The usage of coal for boiling conducts to a considerable amount of fly ash, which is supplied to the cement industry.

Likewise, the water is treated and cleaned of residual material and used by the neighbouring farms. The paper is packed and transported to the retailer, who will be responsible for selling it to the client.

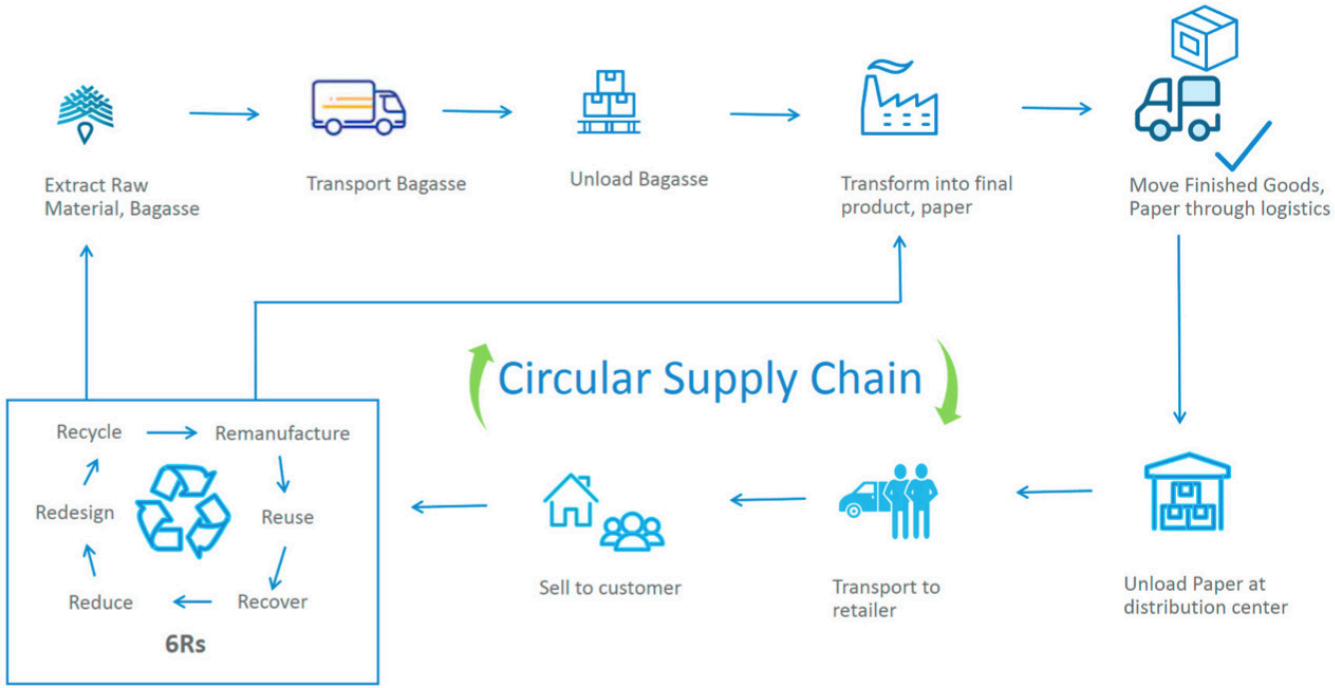

Figure 9: Circular supply chain by Manavalan
Source: Manavalan, 2019

Who?	Manufacturer
What?	Design a trajectory for residual waste. Gives this residual waste to another
Why?	Creates circularity and avoids waste
Where?	Manufacturing industry
When?	After pulp fermentation

Who?	Manufacturer
What?	The burning coal generates a high volume of fly ash, which is supplied to local cement
Why?	Creates circularity and avoids waste
Where?	Manufacturing industry
When?	After burning the coal

Who?	Manufacturer
What?	Steam is formed during the boiling process. The steam is reused to
Why?	Reduce their plant energy consumption or cooking food for employees.
Where?	Manufacturing industry
When?	Boiling the paper

Who?	Manufacturer
What?	The water used by the plant is utilised in irrigation by local farms
Why?	Creates circularity and avoids waste
Where?	Manufacturing industry
When?	At the end of the process

2.3 P1 vs P2 Models by Nasir

Nasir et al. presented the trajectory of two insulation products: P1 (circular) and P2 (linear).
Further, the supply chain of P1, the circular insulation, will be analysed from collecting the denim to finished product.

Yearly, approximately 11,000 t of clothes are collected as the primary material for the production of P1.

The company collects clothes in two different ways: small lories (from 3t to 24t) to the production factories and sea freight for long distances.

The transportation of P1 is still not optimal for limiting carbon emissions because the CO2 released from transport is 6.35% of total emissions compared to 2.51% of P2. In terms of chemical used for product treatment in P1, cotton recycling has lower carbon emissions than the linear model P2.

The fundamental difference between these models is the transformation of the bi-composite polyester binder to a biological binder for reducing CO2 emissions.

The preliminary data indicates that P1's (the circular insulation) emissions are lower than the linear supply chain insulation. (Nasir et al., 2017)

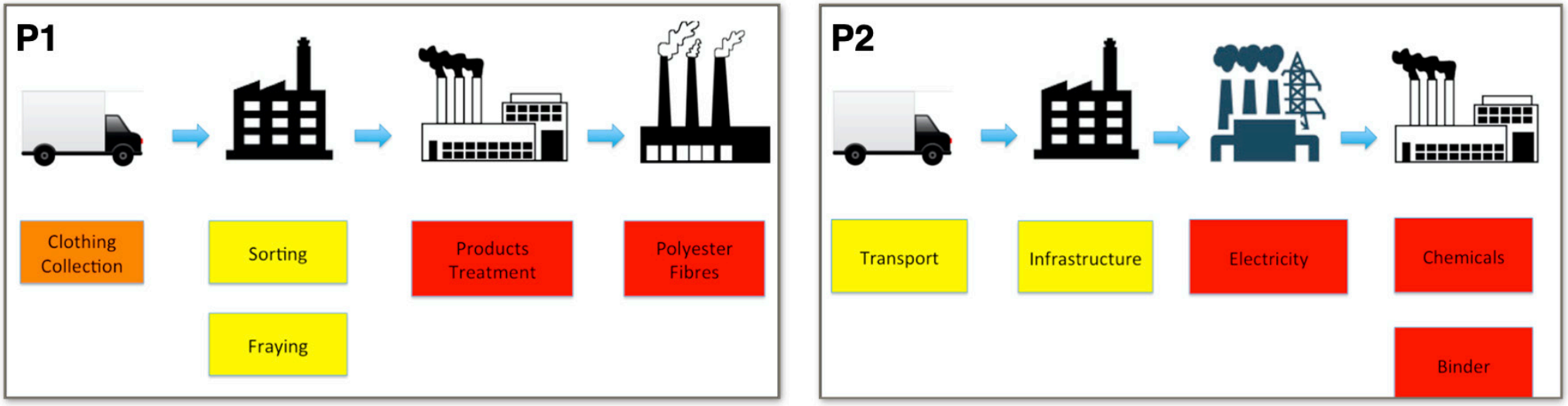

Figure 10: P1 vs P2 by Nasir
Source: Nasir, 2017

Who?	Suppliers
What?	Annually, 11 000 tones of clothes used are collected in the process
Why?	Reducing waste and creating circularity by reusing used product
Where?	Second hand material industry
When?	Each year

Who?	Suppliers->Users
What?	Customers should be correctly informed about circular products
Why?	Increasing the understanding and awareness circular products and sustainability. Clients are tempted to buy insulations based on cheapest price criteria
Where?	Sales domain
When?	Before purchasing the product

Who?	Manufacturers
What?	Transforming the bi-composite polyester binder to a biological
Why?	Optimizing product performance and reducing carbon
Where?	Manufacturing industry
When?	Before starting processing the clothes

Who?	Government
What?	Incentivise the purchasing of circular products financially
Why?	Reducing the environmental harm generated by construction activities like renovation projects
Where?	Public sector
When?	Immediately

2.4 Closed-loop supply chain network designed by Yi

A particular closed-loop supply chain was developed, concentrating on the end of life of construction machinery. Manufacturers and retailers are directly interested in collecting and remanufacturing the used pieces of machinery. By carrying a case study in China, the authors designed an efficient, low-cost supply chain for an important retailer. The retailer has many outlets, a distribution line and a remanufacturing facility.

The construction machinery components present a particular complexity because it requires a preliminary dismantling before remanufacturing. Later, the parts will commence the remanufacturing process divided into five steps: washing, disassembling, sorting, recovery and reassembling.

Here, a specialised dismantling facility is added to the chain for optimising the operations and avoid unnecessary transportation. Severely damaged components are shipped to the Disposal Centers.

The proper components are divided into singular parts and sent to the Dedicated Remanufacturing Centers for the remanufacturing process. The new remanufactured goods are reintroduced in the market cycles through to h the current distribution line.(Yi et., 2017)

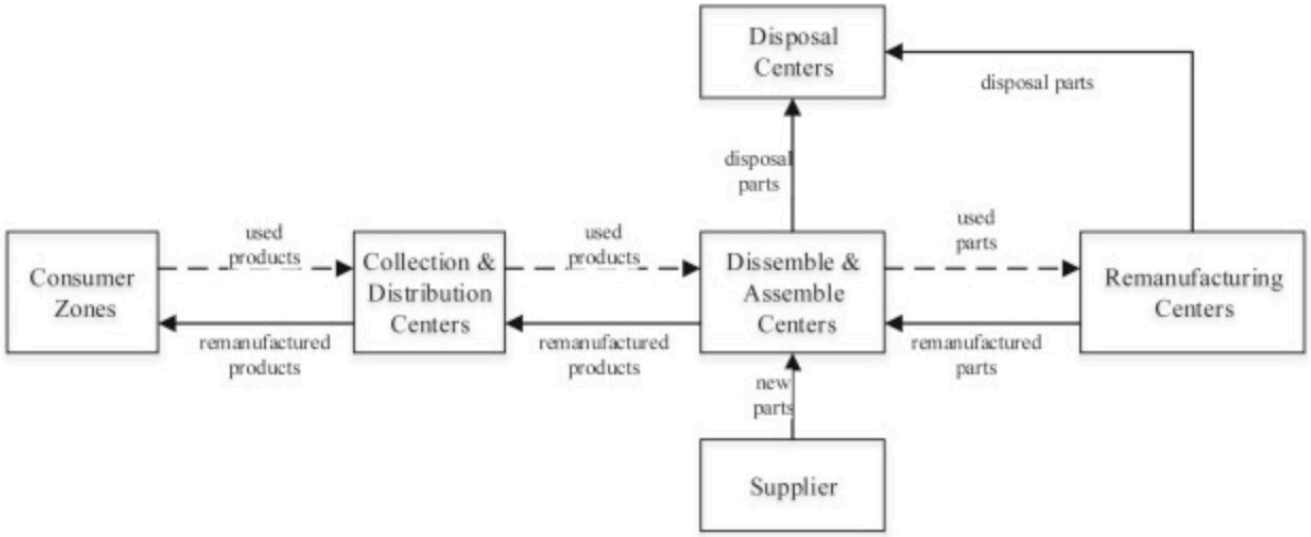

Figure 11: Closed-loop supply chain network designed by Yi
Source: Yi, 2017

Who?	Manufacturers
What?	Will be establish a dismantling center
Why?	To tackle the responsibility of preliminary dismantling of the used components
Where?	Construction machinery sector
When?	The end of the life product

Who?	Manufacturers
What?	The remanufactured products are send back to the market following the route backwards
Why?	To integrate the product in the circular cycle
Where?	Construction machinery sector
When?	After remanucfacturing

Who?	Manufacturers
What?	Only the damaged components are recycled in the Disposal Centers
Why?	To reduce the energy consumption
Where?	Disposal Centers/ Recycling industry
When?	The end of the life product

2.5 Circular supply chain by Jeihoonian

The authors examined a closed-loop supply chain of durable products using the principle of modularity.
The proposed supply chain is based on the manufacturers' existing forward supply chain, containing suppliers, manufacturing centres, distribution lines, and potential end-users.

The new durable products are sent from the manufacturer centre to end-users using the distribution infrastructure. After the end of life product, the used products are received in collection centres, starting the reverse chain.

The role of collection centres is crucial in this supply chain because they evaluate, sort and distribute the components to recovery facilities according to their condition, function or needs.

Only if a component is not fitted for remanufacturing it would be sent to recycling.

Finally, the recovered products are reintroduced in the forward supply chain. Furthermore, the authors proposed a legislative initiative to oblige companies to aim to recover used products.

In the end, authors proposed a legislative initiative to oblige companies to aim to recover used products.(Jeihoonian et al., 2017).

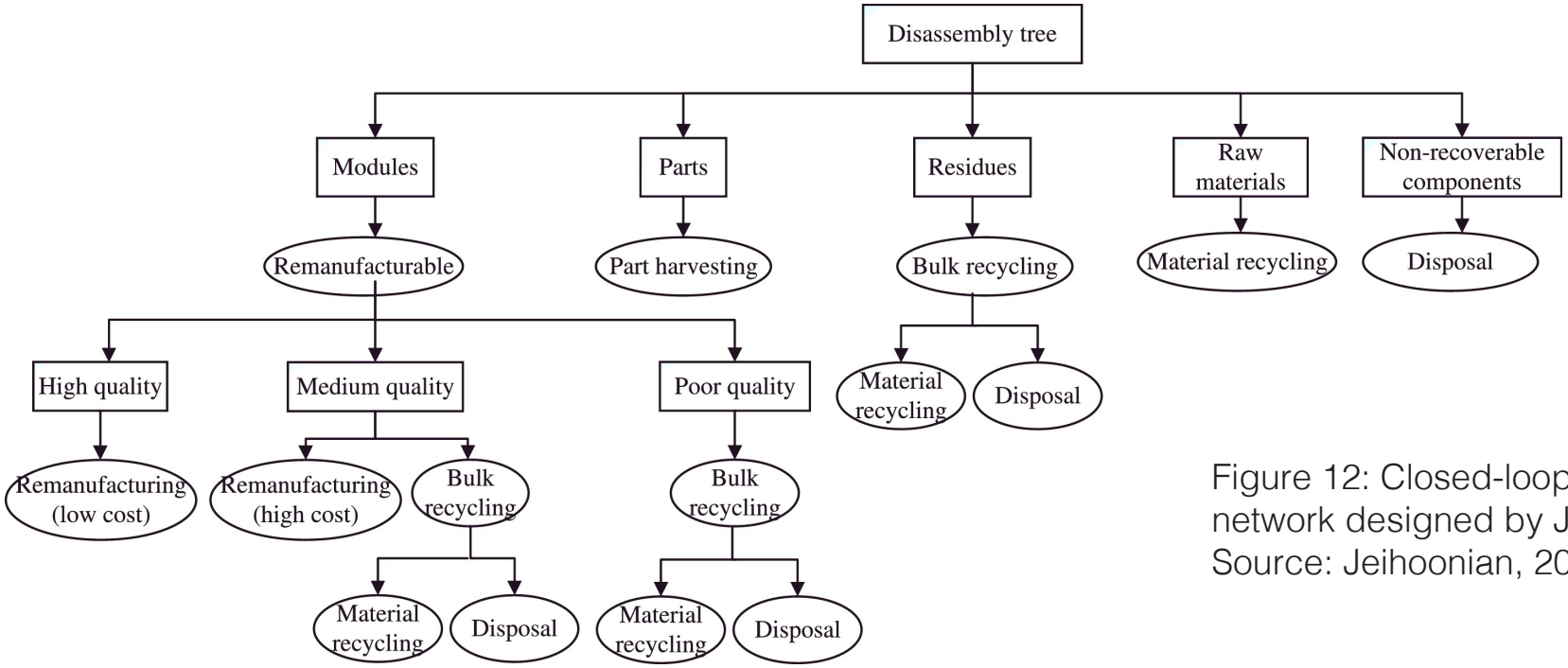

Figure 12: Closed-loop supply chain network designed by Jeihoonian
Source: Jeihoonian, 2017

Who?	Manufacturers
What?	The collection centres evaluate, sort and distribute the components to recovery facilitie.
Why?	To make the process more efficient by sending the parts precisely to right destination
Where?	Manufacturing industry
When?	The end of the life product

Who?	Manufacturers
What?	Only the non-qualitative or unrecoverable Components are sent to recycling.
Why?	To reduce the energy consumption according to Butterfly Model
Where?	Recycling industry
When?	The end of the life product

Who?	Central authorities
What?	Companies should be obliged to recover a proportion of their used products
Why?	Minimise waste and reduce consumption of raw materials
Where?	Legislative area
When?	Soonest possible occasion

2.6 Closed-loop supply chain network by Darestani and Hemmati

The next circular supply chain focusses on perishable goods and tries to reduce the whole chain costs and decrease greenhouse emissions. The proposed supply chain has eight stages of completing a closed-loop supply chain: raw material supplier, producer, distribution centers, retailer, costumer, collection centres, recycling centres and destruction centres.

The suppliers provide raw material to production centres, offering discount according to the quantity ordered. The producers manufacture and deliver the goods to the distribution centres, which store them. The retail centres are purchasing the products and sell them further to the customer. In the reverse supply chain, the used components are returned to the collection centres for evaluation and sorting. The functional components are sent to production centres, while the degraded ones are given to destruction centres.(Darestani et al., *2019*

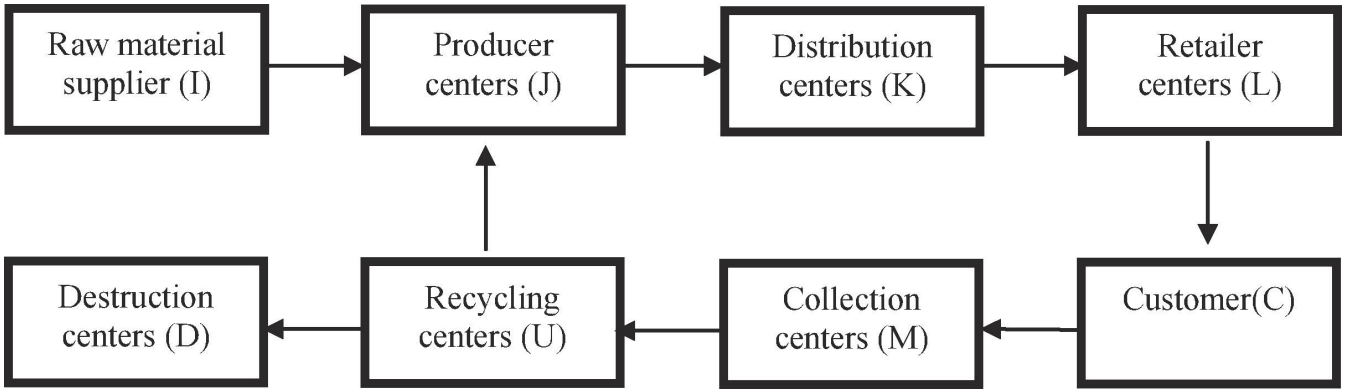

figure 13: *Closed-loop supply chain network by Darestani and Hemmati*
source: *Darestani*, 2019

Who?	Manufacturers
What?	The manufacturer uses distribution centres for storing and delivering the products
Why?	The manufacturer can buy a larger quantity from the supplier to reduce the costs
Where?	Manufacturing industry
When?	During the product production

Who?	Manufacturers
What?	The used products are returned to the collection centres for evaluation and sorting
Why?	To chose the components which can be reused, recycled or destroyed
Where?	Recycling industry
When?	The end of the life product

To sum up, I consider the models of the circular supply chain acquired from the literature are valuable for the research because it presents potential approaches for the Circular Skin supply chain. The significant approaches which might be applied in the construction of the variants for the Circular Skin are:

- The design should ensure durability, flexibility, reuse and deconstruction;
- Product passports for recovering the component at the end of its lifespan;
- Demolition companies could expand their activity portfolio with disassembling activities and reuse material provides;
- Banks/investment fund should use circular criteria parameters to evaluate a project investment;
- Developers could use leasing models, moving their assets from CAPEX to OPEX;
- 6 R's: Recycle, Remanufacture, Redesign, Reuse, Recover, Reduce;
- For every possible residual is found another purpose for minimising the waste;
- Use close-by suppliers and support local businesses;
- Prepare facilities for collecting, sorting and remanufacturing the used products;
- Increase the awareness of the user about circular products;
- The government should financially incentivise the purchase of circular products;
- Introduce a legislative initiative to ask companies to aim to recover used products.

3. Existing literature regarding possibilities and limitations of stakeholders on the circular supply chain

This subchapter will determine and present the possibilities and limitations of stakeholders in the process of implementing various products in a circular supply chain. This step is necessary to address the objective of the graduation report and answer the main research question.

The circular economy has received constant attention from the academic field, economic entities and policymakers as a bright solution to encourage sustainability and a green economy. (Murray, Skene, and Haynes 2017) However, a few considerable challenges may counter the achievement of the circular economy benefits, hampering the transition from linear to CE. (van Loon, Delagarde, and Van Wassenhove, 2018). For example, the literature presents explicitly the concerns about issues like ratio quantity/quality, returns of circular products in closed-loop supply chains, transport or planning for remanufacturing. (Linder and Williander 2017).

Bressanelli et al. analysed, through a systematic literature review, the transition of four different companies from a linear to a circular supply chain. The authors identified seven different categories of challenges: economic and financial viability, market and competition, product characteristics, standards and regulation, supply chain management, technology and users' behaviour. Moreover, a different study has presented another outlook on implementing a circular economy based on three dimensions: economic, environmental and social. CE narrows the material flow to a level that nature tolerates and utilises ecosystem cycles in economic cycles by respecting their natural regenerative capacity. (Korhonen, 2018) Furthermore, Widmer performed another relevant analysis of multiple business models of the circular economy. The BMs are evaluated based on 26 criteria divided into three broad categories: economic value, process activities and stakeholders' involvement.

After examining Bressanelli's, Korkonen and Widmer articles about the implementation of Circular Supply Chains in multiple projects, the framework of chain elements was designed with different categories of possibilities and challenges experienced by stakeholders.

Through a systematic literature review, these circumstances (possibilities and limitations) were divided into two distinct categories of opportunities and challenges, which could help or hamper the circular supply chain. The categories of circumstances that may occur in the stakeholder's activity are divided into two parts: direct components of the supply chain management and factors that will influence the supply chain. By studying the table, the reader can easily find out the information, and it is an efficient way to summarise the data about the possibilities and limitations.

Figure 14: the framework of chain elements
Drawing by the author

3.1 Supply chain management components

Supply chain management is the generic name of the category that encapsulates a wide range of activities that encounter during the transformation of raw materials into final products. It represents the active business process, which maximises customer value and increases the competitive market advantage. Supply chain covers the whole cycle from production to product development to the infrastructure needed to direct these actions. (Hayes, 2019)

In terms of the circular supply chain, the following aspects should be analysed:

- Partner suppliers
- The source of materials
- Re.Manufacturing
- Transportation
- The return flow

3.1.1 Partners suppliers

Partners suppliers		
Type of circumstance	Situation	Source
Limitation	The *availability of suitable partners* represents a challenge in the transition towards CE	Rauer and Kaufmann, 2015
Limitation	Different expertise or commitment.	Walker et al., 2008
Limitation	The process of shifting from a linear to a circular supply chain is uncertain.	Gupta, 2018
Limitation	The lack of information generates resistance and hesitation among stakeholders	Lewandowski, 2016
Possibility	For adoption CE: stakeholders collaboration and social perspective should be part of a holistic approach	(Geissdoerfer et al., 2017)
Possibility	Transition towards a circular supply chain is facilitated by the existence of a shared vision of stakeholders: common approach and responsibilities	Farla et al., 2012
Possibility	The common approach of stakeholders demands a collaborative stand for determining the most sustainable practices.	Jackson et al., 2014

The majority of limitations focusses on the the availability of suitable partners represents a fundamental challenge in the transition towards a circular economy (Rauer and Kaufmann, 2015) because the companies that are active in the circular economy field have difficulties in finding partners with similar expertise or same commitment. (Walker et al., 2008) Another critical challenge that the stakeholders are facing is the uncertainty present in the process of shifting to a circular supply chain. (Gupta, 2018) The uncertainty is generated by the lack of various information regarding circularity in the building industry; it creates resistance and hesitation among the stakeholders. (Lewandowski, 2016) For Circular Skin, the availability of suitable partners could be problematic, because the construction companies might not have same commitment to the circularity cause.

On the other hand, there are several possibilities for stakeholders to build a circular supply alongside their partners. Multiple studies have proved that Circular Economy could be adopted if stakeholders collaboration and social perspective are integrated into a holistic approach, where all the stakeholders are aiming for similar values: circularity, sustainability and durability. (Geissdoerfer et al., 2017) A smooth transition towards a circular supply chain is facilitated by the existence of a shared vision of stakeholders. The stakeholders should have to find together a strategy and should determine their long term responsibilities. (Farla et al., 2012) The conventional approach of stakeholders demands a collaborative stand for choosing the most sustainable practices relating to technical, social and administrative manner. (Jackson et al., 2014). For Circular Skin, the stakeholders of the REHAB project could represent a solid groundwork for establishing a holistic approach based on similar values and common approach.

3.1.2 The source of materials

The limitations are foccused on the secondary raw materials source discussing the problems of availability, uncertain quality and absence of information.
The analysis made by Leipold et al. showed that unavailability of secondary raw materials is a fundamental issue for the stakeholders who are willing to implement the circular economic model. (Leipold, 2018) The secondary raw materials are recycled materials which can be reused instead of virgin raw materials. Besides the unavailability, another obstacle for the stakeholders is the uncertain quality of the secondary raw materials, because of the lack of international standards for ascertaining the impurity levels and suitability for recycling (for example plastics). (EU Circular Economy Action Plan, 2015) The modularity of the Circular Skin will offer the opportunity of reusing the components, but one of limitation might be the uncertain quality.

On the flip side, the possibilities are directed to the idea that circular

economy promotes a fair usage between the finite resource and renewable raw materials. Stakeholders shall extend the circularity of materials and components as much as possible and limit harmful external sources of production, consumption and waste. (EMF, 2015) The advocacy for sustainable cycles, not using toxic materials and tracking chemicals will encourage recycling and developing uptake of secondary raw materials. (EU Circular Economy Action Plan, 2015) Construction and demolition represent valuable sources of waste in Europe. This issue could be used as an opportunity for creating a possible source of circular materials. However, useful materials and components are often ignored, collected with irrecuperable waste, not separated, and their potential is not fully exploited. (EU Circular Economy Action Plan, 2015) The materials resulted from the dissasembling of Circular Skin are a possible source of components and non-virgin matarials.

The source of materials		
Type of circumstance	Situation	Source
Limitation	Unavailability of secondary raw materials is a main issue for the stakeholders who are willing to implement CE.	Leipold, 2018
Limitation	The uncertain quality of the secondary raw materials is an obstacle, (for example: plastics).	EU Circular Economy Action Plan, 2015
Limitation	Insufficient information exchange between manufacturers and recyclers of electronic products, the absence of recycling standards, and a lack of data for economic operators on the potential for recycled critical raw materials are barriers for the stakeholders	EU Circular Economy Action Plan, 2015
Possibility	CE encourages a balanced usage between the finite reserve and renewable raw materials. Stakeholders shall extend the circularity of materials and components as much as possible and limit negative external sources of production and consumption	Ellen MacArthur Foundation, 2015
Possibility	Encouraging sustainable cycles, not using toxic materials and tracking chemicals will promote recycling and developing uptake of secondary raw materials.	EU Circular Economy Action Plan, 2015
Possibility	The materials resulted from demolition are possible source of circular materials.	EU Circular Economy Action Plan, 2015
Possibility	Useful materials and components are often ignored, collected with irrecuperable waste, not separated and their potential is not fully exploited.	EU Circular Economy Action Plan, 2015

3.1.3 Re/Manufacturing

The literature widely recognises the limitations regarding uncertainties about manufacturing. The stakeholders' concerns are mainly focussed on quantity, quality and product return. For example, in closed-loop supply chains, the uncertainties are represented by the planning delays in the renovation activities, such as remanufacturing. (Linder and Williander, 2017) According to Pheifer, following an organisational angle, manufacturing a circular product is more expensive in terms of initial manufacturing costs that a linear one because of the complicated handling and materials. For example, using screws is more costly than to glue the product, but it will make possible the reparation of the component. (Pheifer, 2017) The Circular Skin manufacturing might be affected by uncertainty regarding the return of components, because the source of used components is time unstable.

Manufacturing		
Type of circumstance	Situation	Source
Limitation	The stakeholder's concerns are focussed on uncertainties represented by the planning capacity for renovation activities, such as remanufacturing.	Linder and Williander, 2017
Limitation	Manufacturing a circular product is more expensive in terms of initial manufacturing cost than a linear one because of the complex handling and materials. (Using screws over glue)	Pheifer, 2017
Possibility	By implementing circularity in the manufacturing sector, the stakeholders will gain a positive public perception, which could be used as marketing leverage.	Ellen MacArthur Foundation, 2015
Possibility	Ellen MacArthur Foundation presented an analysis, which included factors like collection, transport, disassembly and initial screening and resulted cost savings of 50% for remanufacturing compared to producing a new product	Ellen MacArthur Foundation, 2015
Possibility	Stakeholders have the possibility to use the recycling of residual material inside of Europe (because of illegal export of waste), creating jobs locally	Ellen MacArthur Foundation, 2015

In contrast, remanufacturing serve as significant possibilities for stakeholders involved in circular supply chains. By implementing circularity in the manufacturing sector, the stakeholders will earn a positive public perception, which could be used as marketing leverage. (EMF, 2015) Ellen MacArthur Foundation presented an analysis, which included factors like collection, transport, disassembly and initial screening and resulted in cost savings of 50% for remanufacturing compared to producing a new product. (EMF, 2015) Another possibility for stakeholders during the manufacturing process is the opportunity to use the recycling of residual material inside of Europe (because of illegal export of waste), generating employment locally. (EMF, 2015) For the Circular Skin, the remanufacturing of used products could determine cost savings simultaneously with respecting the principle of circularity.

3.1.4 Transportation

Transportation		
Limitation	In a circular supply chain, the transportation costs increase because the components should be collected and *transported* from a manufacturing centre towards an end-of-use location and backwards after the end of the product's lifespan.	Bakker et al. 2014
Limitation	Indirect transport has been proven to emit more CO2 emissions than the direct transport.	Prosman, 2018
Possibility	The stakeholders has the possibility to diminish the carbon emissions by selecting a close-by supplier for limiting the indirect transport	Tasca et al., 2015

Transportation is a harmful necessary action because it affects the environment by producing CO2 emissions, but the harm could be minimised if it is managed correctly.

For Circular Skin's transportation, the components should be collected and transported from a manufacturing centre towards an end-of-use location and backwards after the end of the product's lifespan. According to Bakker, in a circular supply

chain, transportation costs increase. Furthermore, the transportation sector presents a negative environmental impact, which will undermine the circular economy's greater-good goal. (Bakker et al. 2014)

Prosman and Sacchi made a distinction between direct and indirect transport. Direct transport represents the carriage between the buyer and the first supplier, while indirect transportation is a consequence of long-distance trade operations between different markets. Indirect transport has been proven to emit more CO2 emissions than direct transport, representing a real challenge. (Prosman, 2018).

However, the stakeholders of Circular Skin have the possibility to reduce the CO2 by selecting a close-by supplier for limiting indirect transport. (Tasca et al., 2015)

3.1.5 Return flow

Return flow		
Type of circumstance	Situation	Source
Limitation	The stakeholders worries are related to the uncertainties about return flow	Linder et al., 2017
Limitation	Uncertainties reduce the chances of achieving an economical scale in the circular renovation activities	Kumar and Putnam, 2008
Possibility	Stakeholders could use an financial incentive	Wojanowski et al., 2007
Possibility	Efficient public communication could increase the awareness	Lieder et al., 2018
Possibility	Eco-labelling and sustainability certification could influence the user's behaviour	Masi et al., 2017

The limitations regarding return flow are related to uncertainties, whilst the possibilities represent solutions to encourage the user to complete the loop and return the products to the manufacturer.

The stakeholder's worries are related to the doubts about quantity, quality and timing of product return. The uncertainties regarding the recovery in the closed-loop supply chains, for example, could determine imprecision in planning for renovation and remanufacturing. (Linder et al., 2017) Furthermore, uncertainties about quantity, quality, timing and location of return reduce the chances of achieving an economic scale in the circular renovation activities. (Kumar and Putnam, 2008)

One possible solution for the stakeholders could be a financial

incentive for the product take-back, such as the deposit-refund scheme, for decreasing the return uncertainty level. (Wojanowski et al., 2007) Furthermore, efficient public communication could increase the population's awareness level for determining them to with the circular principle of returning the product. (Lieder et al., 2018) On this point, eco-labelling and sustainability certification could influence the client's behaviour to return their product. (Masi et al., 2017)

Circular Skin is dependent on an efficient return flow, so uncertainties should be removed through any solution like incentives, public communication or marketing strategies.

3.2 External factors that influence supply chain

The other categories of circumstances that may occur in the stakeholder's activity are the factors that will influence the supply chain. The factors are:

- Economic feasibility
- Product design
- Regulation
- User's behaviour

3.2.1 Economic feasibility

The economic limitations of a circular are related to financial uncertainty and risks distribution, whilst the possibility presents an optimistic view that circularity has been emerging in the market lately.

Three distinctive challenges have been found for the economical category: time mismatch between revenue and cost streams, financial risk and operational risk. (Bressanelli et al., 2018) One of the main challenges for implementing a circular supply chain in the construction industry is the financial uncertainty due to lack of clarity in the foresight of incomes, "which ranked number one for the majority of stakeholders". (Adams et al., 2017) Furthermore, according to Baines et al. in the serviced industry, which is also applicable for the Circular Skin, both financial and operational risks are transferred from the client to the provider. (Baines and al., 2013)

According to Korhonen, the efficiency of processing existing used materials, like reuse, remanufacture, refurbish or recycle, has continuously been increasing over time. The change in the consumption culture of sharing economy, like product reuse, is beneficial for stakeholders involved in the circular economy. (Korhonen et al., 2018) For example, McKinsey & Company developed an economic recovery and reuse model for plastics to design process flows. This model contains costs evaluations, direct recycling benefits, material-recycling systems, range of target costs and possibilities to identify the bottlenecks. (Gao et al., 2020)

The implementing of Circular Skin could be seriously hindered by uncertainty regarding the incomes. If a manufacturer leases the facade, both financial and operational risks are transferred from the user to the manufacturer.

Economic feasibility		
Type of circumstance	Situation	Source
Limitation	Time mismatch between revenue and cost streams, financial risk and operational risk.	Bressanelli et al. , 2018
Limitation	The financial uncertainty due to lack of clearness in foresight the incomes	Adams et al., 2017
Limitation	In the serviced industrythe risks, both financial and operational, are transferred from the client to the provider	Baines and al., 2013
Possibility	The efficiency of processing existing used materials, like reuse, remanufacture, refurbish or recycle,	*Korhonen et al., 2018*
Possibility	McKinsey & Company developed an economical recovery and reuse model for plastics to design process flows.	*Gao et al., 2020*

3.2.2 Product design

Product design		
Type of circumstance	Situation	Source
Limitation	Long lasting design might fail to respond fashion changes, resulting in demand decrease.	Linder and Williander, 2017
Limitation	The renovation or restoration difficulty increases proportionally with the product complexity.	Despeisse et al., 2017
Possibility	Strategy in in 4 steps	Govindan et al., 2015
Possibility	An efficient product design can contribute to sustainable consumption of materials and energy saving.	Laurenti et al., 2015
Possibility	Designers should be encouraged to use innovative chemical degradation of products in time for reducing the planetary waste.	Clark et al., 2016
Possibility	DFD has been proven in multiple industrial sectors to be a technological advancement	Sabaghi et al., 2016

The product design is one of the supply chain elements that offers more possibility than limitations in terms of circularity. The design of the circular components should provide long-lasting use despite the linear model take-use-throw away.

A possible consequence might be the inability to respond to fashion changes, resulting in the demand decrease. (Linder and Williander, 2017) Furthermore, the renovation or restoration difficulty increases proportionally with product complexity. (Despeisse et al., 2017)

On the other hand, stakeholders have numerous possibilities to shift from a linear to a circular supply chain by enhancing a circular design. Govindan, Soleimani, and Kannan presented an exhaustive circular design strategy in 4 steps for reducing environmental impact: (Govindan et al., 2015)

- The inner cycles shown in Butterfly Model (EMF, 2013) should be preferred over the broader cycle processes, for example, reuse and recover should be prioritised over recycling

- Slowing the resource cycles: the lifespan of the products and components should be extended to its maximum possible

- The waste should be diminished at every lifecycle

- The stakeholders should be focussed on reducing, reuse, recycle and recover resources (Govindan et al., 2015)

Efficient product design for circular supply chain can contribute to

sustainable consumption of materials and energy saving. (Laurenti et al., 2015) Furthermore, designers should be encouraged to use innovative chemical degradation of products in time for reducing the planetary waste. (Clark et al., 2016) Additionally, implementing design for dismantling (DFD) has been proven in multiple industrial sectors to be a technological advancement that will expand the lifespan of a product, support maintenance and facilitate separation of components for recycling (for example, polymers). (Sabaghi et al., 2016)

The Circular Skin design is finalised, but it might be optimised according to the supply chain. The limitations are insignificant compared to the design possibilities. I consider design to dismantle the most suitable solution for Circular Skin because it will facilitate the reuse of components, encourage efficient consumption of materials, and reduce waste.

3.2.3 Regulation

Regulation		
Type of circumstance	Situation	Source
Limitation	Current legislation encourages more recycling rather than reuse or repair	Kissling et al. 2013
Limitation	Possible financial incentives are incorporated in the current taxation system.	Al Zaabi et al., 2013
Possibility	To stimulate CE, industry sectors that use non-renewable resources should have higher taxation	Stahel, 2013
Possibility	Main goal is to develop an economy which preserve the value of products as long as possible and minimise waste.	European Commission, 2015

The limitations in the regulation are connected to existing legislative and taxation systems, whilst the possibilities are modifications to the current regulation for encouraging circular economy.

Existing legislation on the circular supply chain is limited and encourages more recycling than the activities that will preserve more product value, like reuse or repair. (Kissling et al. 2013) Possible financial incentives are incorporated in the current taxation system, limiting the options for stakeholders to promote the circular economy. (Al Zaabi et al., 2013) To stimulate CE, industry sectors that use non-renewable resources should have higher taxation levels than sustainable economic activities. (Stahel, 2013)

Fortunately, the EU Circular Economy Action Plan, in 2015, opened a new avenue for implementing a circular

economic model in Europe. This plan's main goal was to develop an economy that preserves the value of products as long as possible and minimises the amount the waste. (European Commission, 2015)

The implementation of Circular Skin could be eased by adjusting regulation, like tax reduction or macro-environmental policies.

3.2.3 Regulation

Regulation		
Type of circumstance	Situation	Source
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Limitation	Possible financial incentives are incorporated in the current taxation system.	Al Zaabi et al., 2013
Possibility	To stimulate CE, industry sectors that use non-renewable resources should have higher taxation	Stahel, 2013
Possibility	Main goal is to develop an economy which preserve the value of products as long as possible and minimise waste.	European Commission, 2015

I consider the User's behaviour a decisive element of the supply chain in deciding if the network is circular or not. Circular Skin could be a servitised product, and the users might be attracted or develop a careless behaviour towards a leased product.

Leased (servitised) products that usually offer access instead of ownership might not be attractive to some users. (Rizos et al., 2016). Furthermore, users might develop careless behaviour towards the servitised products, while they do not personally own the product. As a direct consequence, extra repairing and maintaining costs might arise, generating relational tensions between supplier and client. (Barquet et al. 2013)

A study performed by Nasir et al. showed that customers' concerns are more related to the price and

performance of the product rather than the environmental benefits of its circular supply chain. (Nasir et al., 2016) Lastly, data privacy and security represent factors that limit the return of products. For instance, users are concerned to return their laptops or devices for not compromising their personal information. (Saidani et al., 2018)

In conclusion, in this section, I found and presented the possibilities and limitations of stakeholders in implementing various products in a circular supply chain. Certainly, not of all them are directly applicable for Circular Skin but will serve as guidance for constructing the supply chain variants during a Charrette day. For example, to reduce stakeholders' uncertainties about the quality or provenance of components, the variant will include the possibility of introducing a material passport.

VI. Synthesis phase

The possibilities and limitations identified in the previous chapters are used as guidance to create variants of the circular supply chain for the Circular Skin during a Charrette day. The Charrette is a method for an intense designing of the circular variants by both students and professors from TU Delft. The researcher presented his intermediate results: the current linear supply chain for building projects, description of the circular skin and examples from the literature of circular supply chain. Following the knowledge derived from the analysis, five circular variants of the supply chain for the Circular Skin were produced:

- User-oriented
- Sell and buyback
- Sell and buyback without a contractor
- Product as a service
- Vertical supply chain integration

1. User oriented variant

This variant of supply chain places the user in the middle of operations because the user holds the total ownership of the Circular Skin. The customers have the possibility to check the retail store offer and decide what type of facade they want to buy according to their needs (dimensions, thickness, finishing layers). The clients will receive quality customer service for calculating the materials necessary.

In this variant, the manufacturer would procure the materials from different suppliers only after verifying stringent criteria: material sustainability, distribution efficiency, technical quality and possibilities to reintegrate in the circular cycle after the end of product life. Every component of the Circular Skin would have a precise material passport for presenting the traceability of each part from the extraction till manufacturing and the assembling.

After purchasing the Circular Skin, the client becomes the product owner. Under these conditions, the user is responsible for installing the facade by contracting a construction company. The installation technology is simple and does not require a specialized contractor. Furthermore, the maintenance and reparation of the Circular Skin are open-source, the user being entitled to contract different constructors for maintenance services.

At the end of the product lifespan, the user should contact a demolition company to disassemble circular skin. The user has the possibility to sell the components resulted from demolition to a second-hand material broker, securing a possible source of income.

The return flow is an open-loop because the broker will re-sell the components to different manufacture centres, recycling companies or other suppliers.

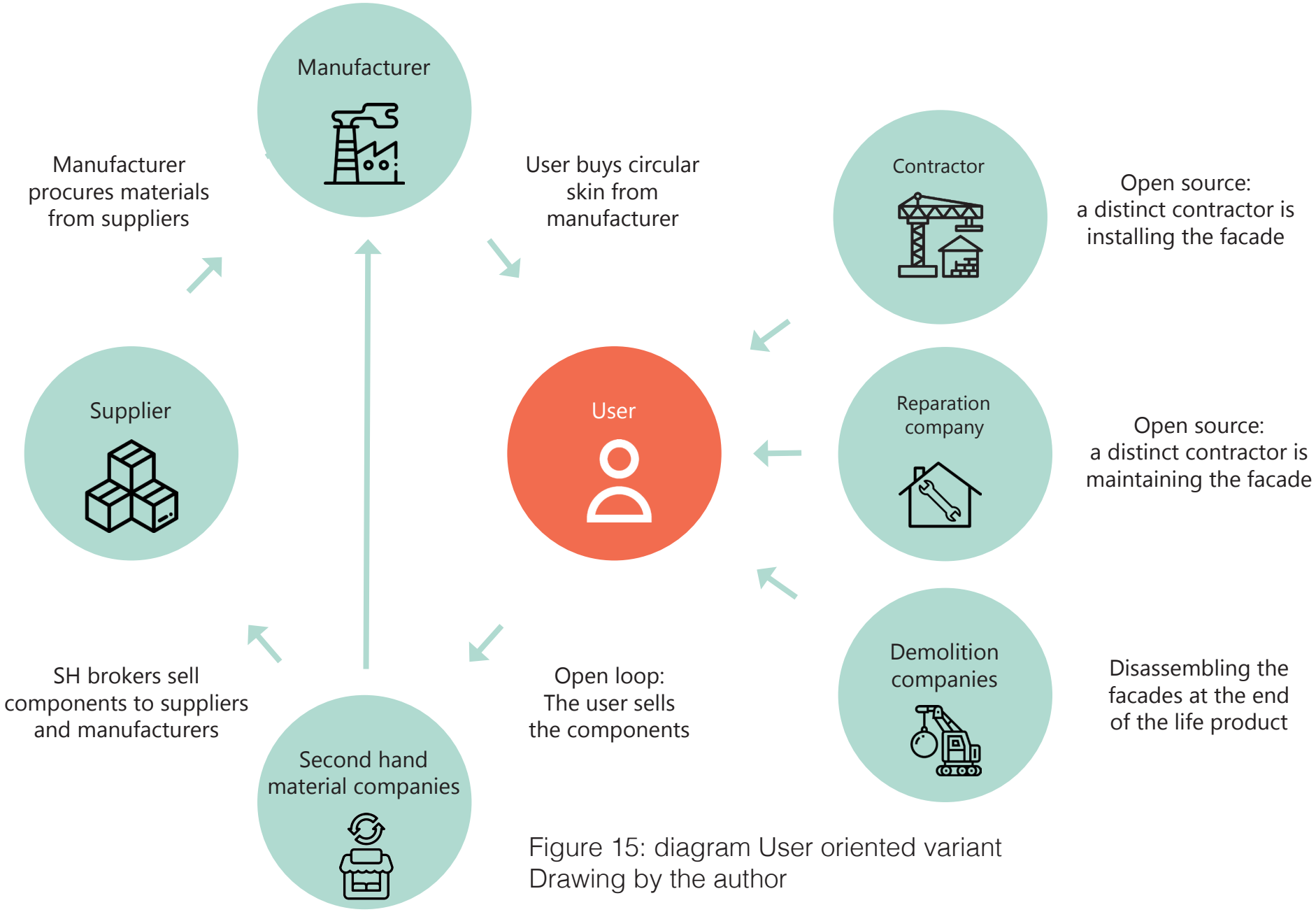

Figure 15: diagram User oriented variant
Drawing by the author

Who?	User
What?	User contracts companies for the maintenance and demolition
Why?	Market competition offers greater selection and better products, causes lower prices
Where?	Maintenance and demolition sectors
When?	After the user buys the product

Who?	Manufacturers
What?	Will create material passport for every product
Why?	A clear traceability of the materials will facilitate the reintroduction in close loop
Where?	Manufacturing industry
When?	Before starting manufacturing process

Who?	Demolition companies
What?	Disassemble the Circular Skin carefully and sort out the materials
Why?	The materials are sold by the user to second hand material broker
Where?	Demolition phase
When?	At the end of lifeproduct

Who?	Government
What?	Incentivise the purchasing of circular products financially
Why?	Reducing the environmental harm generated by construction activities like renovation projects
Where?	Public sector
When?	Immediately

Who?	Contractor
What?	Is contracted separately by the User to install the facade
Why?	Market competition offers better prices and freedom to User
Where?	Construction sectors
When?	After the user buys the product

Who?	Reparation company
What?	Maintain the Circular Skin
Why?	Market competition offers better prices and freedom to User
Where?	Construction sectors
When?	Exploitation phase

Who?	Second hand material companies
What?	Collect the components from the user
Why?	They are ensuring a secondary source of materials for the Manufacturer
Where?	Demolition phase
When?	At the end of lifeproduct

2. Sell and buyback variant

The sell and buyback follow the general characteristics of the user-oriented variant, but it contains several exceptions. The manufacturer procures the materials from different local suppliers for limiting indirect transport. During the purchase, the client would receive technical assistance from the manufacturer.

After purchasing the product, the user can select different contractors to effectuate the installation and maintenance of the facade (open source).

The main difference between sell and buyback and the user-oriented variant is the sale agreement. The contractual purpose is the Circular Skin sale, but the manufacturer will introduce a clause of returning the product. It is essential to stipulate in the contract how will be evaluated or calculated the facade's future value to reduce uncertainty and avoid mistrust between parties.

The manufacturer will offer significant financial motivation for the return of the product, in this way, closing the loop. Furthermore, the manufacturer will provide the disassembling service and return transportation freely to the user.

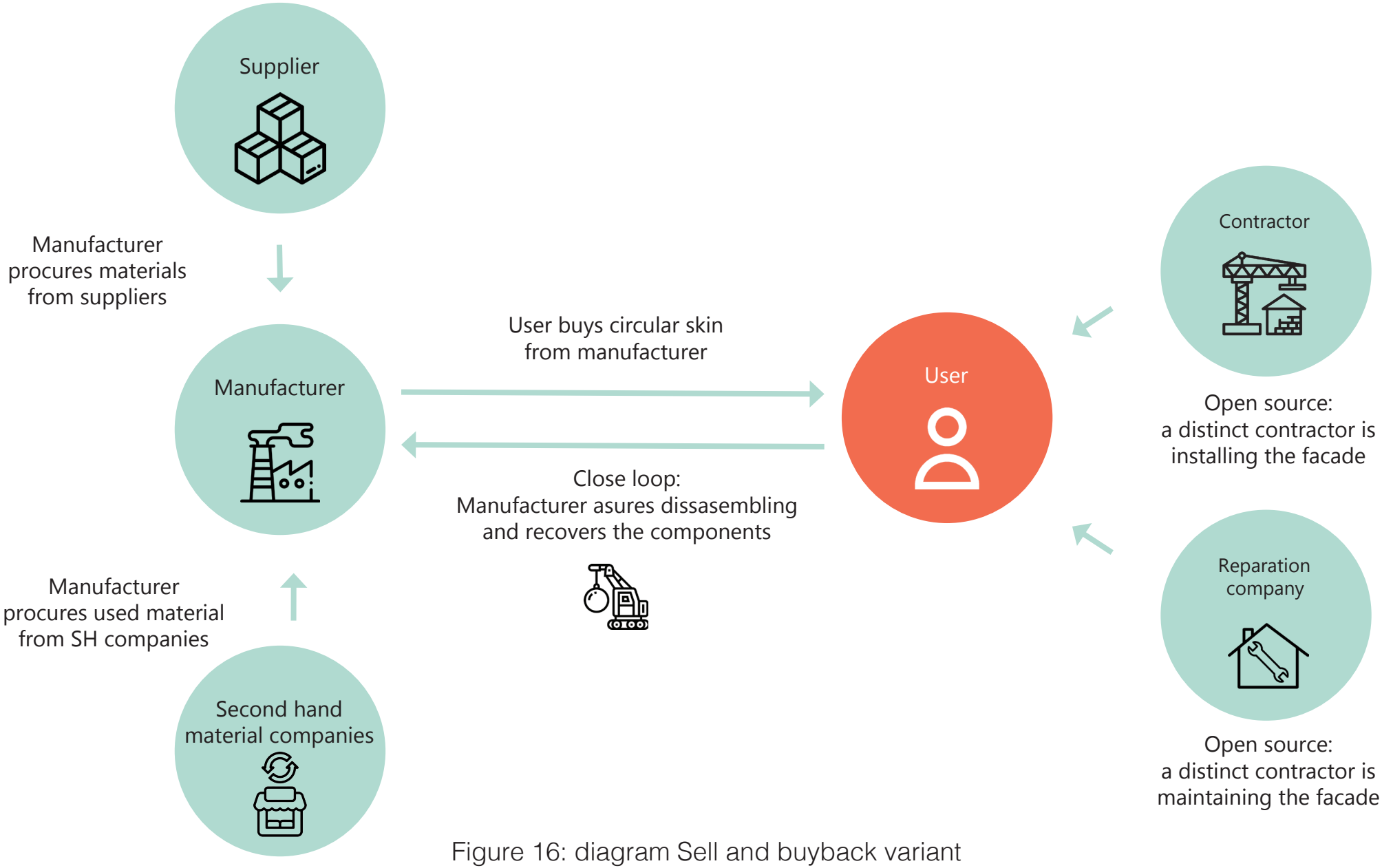

Figure 16: diagram Sell and buyback variant
Drawing by the author

Who?	User
What?	User contracts companies for the maintenance
Why?	Market competition offers greater selection and better products, causes lower prices
Where?	Maintenance sectors
When?	After the user buys the product

Who?	Manufacturers
What?	Will create material passport for every product
Why?	A clear traceability of the materials will limit stakeholder's uncertainty
Where?	Manufacturing industry
When?	Before starting manufacturing process

Who?	Manufacturers
What?	Disassemble the Circular Skin for free and pay for collecting the materials
Why?	Incentivise the user and will generate circularity
Where?	Demolition phase
When?	At the end of lifeproduct

Who?	Government
What?	Incentivise the purchasing and return of circular products financially
Why?	Reducing the environmental harm generated by construction activities like renovation projects
Where?	Public sector
When?	Immediately

Who?	Contractor
What?	Is contracted separately by the User to install the facade
Why?	Market competition offers better prices and freedom to User
Where?	Construction sectors
When?	After the user buys the product

Who?	Reparation company
What?	Maintain the Circular Skin
Why?	Market competition offers better prices and freedom to User
Where?	Construction sectors
When?	Exploitation phase

Who?	Second hand material companies
What?	Collect the components from different sources (not Circular Skin components)
Why?	They are ensuring a secondary source of materials for the Manufacturer
Where?	Demolition phase
When?	At the end of lifeproduct

3. Sell and buyback without contractor variant

The sell and buyback without a contractor is a variant of a circular supply chain, which transfers the construction installation service from the user to the manufacturer.

The most notable aspect is the continuity for the same operator in the main construction processes: manufacturing, installation and disassembling. Furthermore, the manufacturer might develop construction teams for installation and disassemble of the facade.

Consequently, a specialised construction team from the manufacturer would operate the components, reducing the risk of damaging the facade's parts.

In this variant of the supply chain, the user is still the product owner. The manufacturer should create an advantageous climate for determining the user to return the facade by dismantling the facade, transporting the components and offering a fair financial incentive or discount for buying a new facade.

The user is incentivised to return the facade to the manufacturer for closing the loop. Nevertheless, the user is entirely responsible for the maintenance and reparation of the Circular Skin during the exploitation.

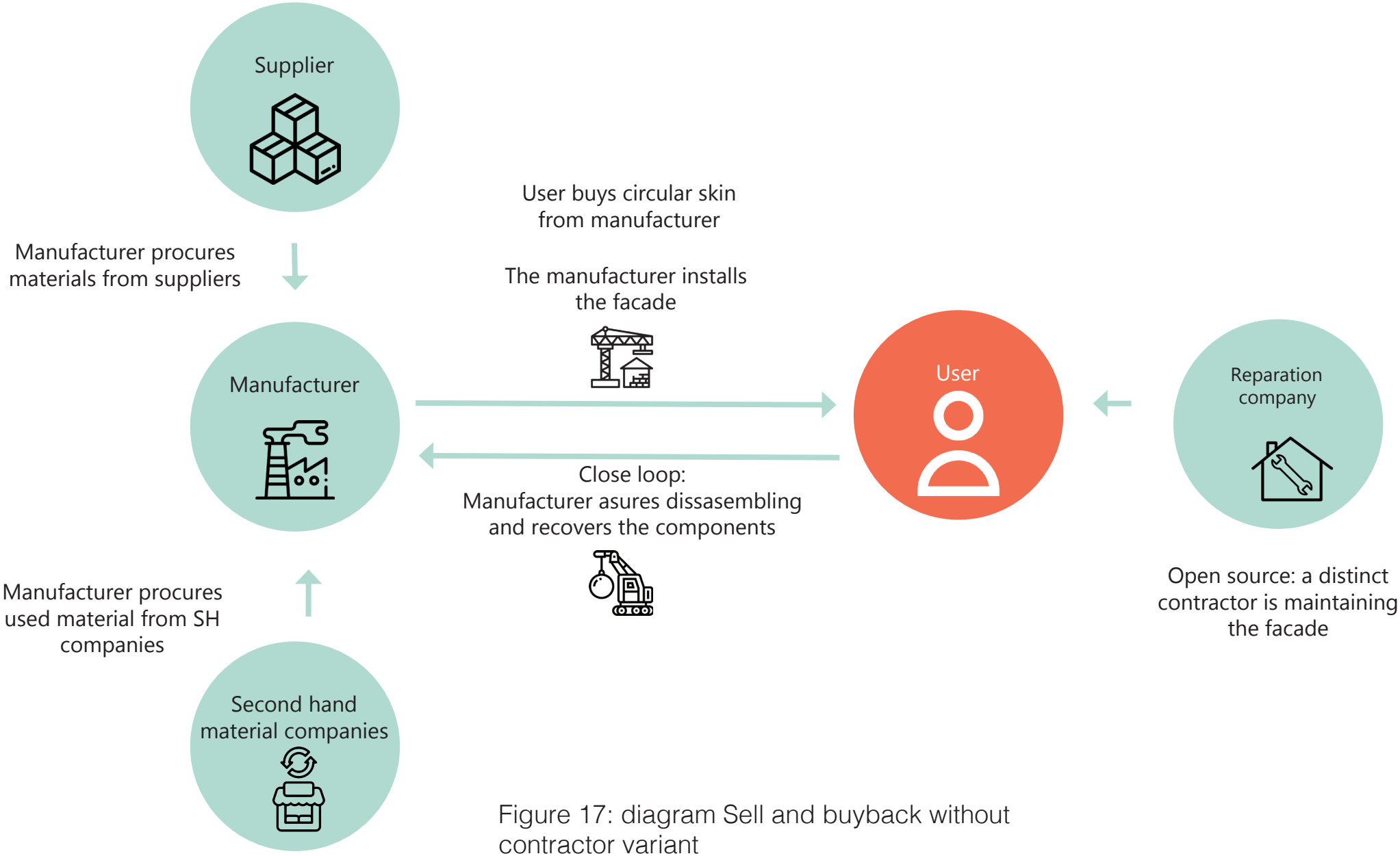

Figure 17: diagram Sell and buyback without contractor variant
Drawing by the author

Who?	User
What?	User contracts companies just for the maintenance (open source)
Why?	Market competition offers greater selection and better products, causes lower prices
Where?	Maintenance and demolition sectors
When?	After the user buys the product

Who?	Manufacturers
What?	Will create material passport for every product
Why?	A clear traceability of the materials will facilitate the reintroduction in close loop
Where?	Manufacturing industry
When?	Before starting manufacturing process

Who?	Manufacturers
What?	Install and disassemble the Circular Skin for free and pay for collecting the materials
Why?	Incentivise the user and will generate circularity
Where?	Installation and demolition phase
When?	At the beginning and theend of lifeproduct

Who?	Reparation company
What?	Maintain the Circular Skin
Why?	Market competition offers better prices and freedom to User
Where?	Construction sectors
When?	Exploitation phase

Who?	Second hand material companies
What?	Collect the components from different sources (not Circular Skin components)
Why?	They are ensuring a secondary source of materials for the Manufacturer
Where?	Demolition phase
When?	At the end of lifeproduct

4. Product as a service variant

As technological advancement reaches out to newer industries, an economic shift is registered: from product to service. Servitization represents selling solutions, services to clients than material products.

In the Circular Skin case, the manufacturer delivers precisely the service to fulfil the user's needs instead of a product. The user is interested in isolating his house, not in possessing the facade. The product ownership is retained by the manufacturer, not the client. The manufacturer of the Circular Skin will perform the roles of seller and lessor simultaneously.

The manufacturer builds the Circular Skin with materials procured from external suppliers. The user leases the facade from the manufacturer in exchange for a periodical (probably monthly) fee. The installation and the maintenance of the Circular Skin will be the responsibility of the manufacturer, creating a closed source supply chain. Furthermore, the return flow is clarified because the manufacturer will disassemble and return the components to the factory. The materials can be easily reused or remanufactured, closing the loop.

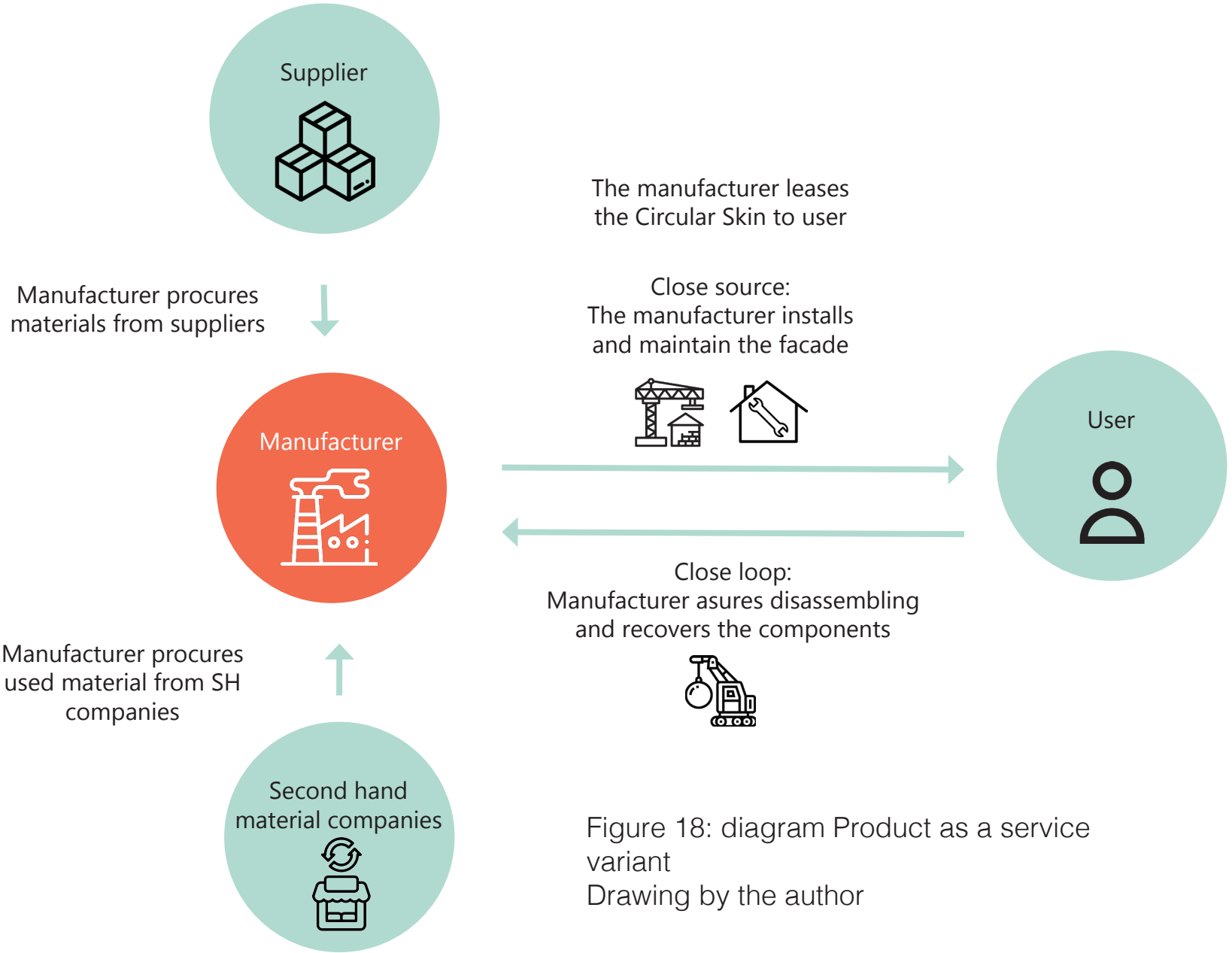

Figure 18: diagram Product as a service variant
Drawing by the author

Who?	Manufacturers
What?	Will be responsible for installation, maintenance and disassemble (closed source)
Why?	Experienced teams will be more productive working with Circular Skin
Where?	Maintenance and demolition sectors
When?	After the user buys the product

Who?	Manufacturers
What?	Reuse and remanufacture the components of the Circular Skin for producing other facades (closed loop)
Why?	Increase circularity, minimise waste and limit resource consumption
Where?	Remanufacture phase
When?	The end of the life product

Who?	User
What?	Leases the Circular Skin from the manufacturer
Why?	Reduce the initial investment, paying just for the service
Where?	Construction sectors
When?	Exploitation phase

Who?	Second hand material companies
What?	Collect the components from different sources (not Circular Skin components)
Why?	They are ensuring a secondary source of materials for the Manufacturer
Where?	Demolition phase
When?	At the end of lifeproduct

5. Vertical supply chain integration variant

The vertical supply chain integration represents a variant where a company owns and control the suppliers, distributors, contractors and manufacturers.

The Circular Skin manufacturer will produce its components (the wood components, bio-skin insulation, connectors and finishes), search for reused insulation products and distribute, construct, maintain, disassembly, recover and remanufacture the facade.

The manufacturer retains the Circular Skin ownership, following the model of the product as a service variant. The manufacture will offer a closed source and closed-loop service, installing, maintaining and recovering the facade components.

This variant is designed for immense corporations with large investment capabilities. This variant requires a significant initial investment, and just a big manufacturer or contractor can afford it.

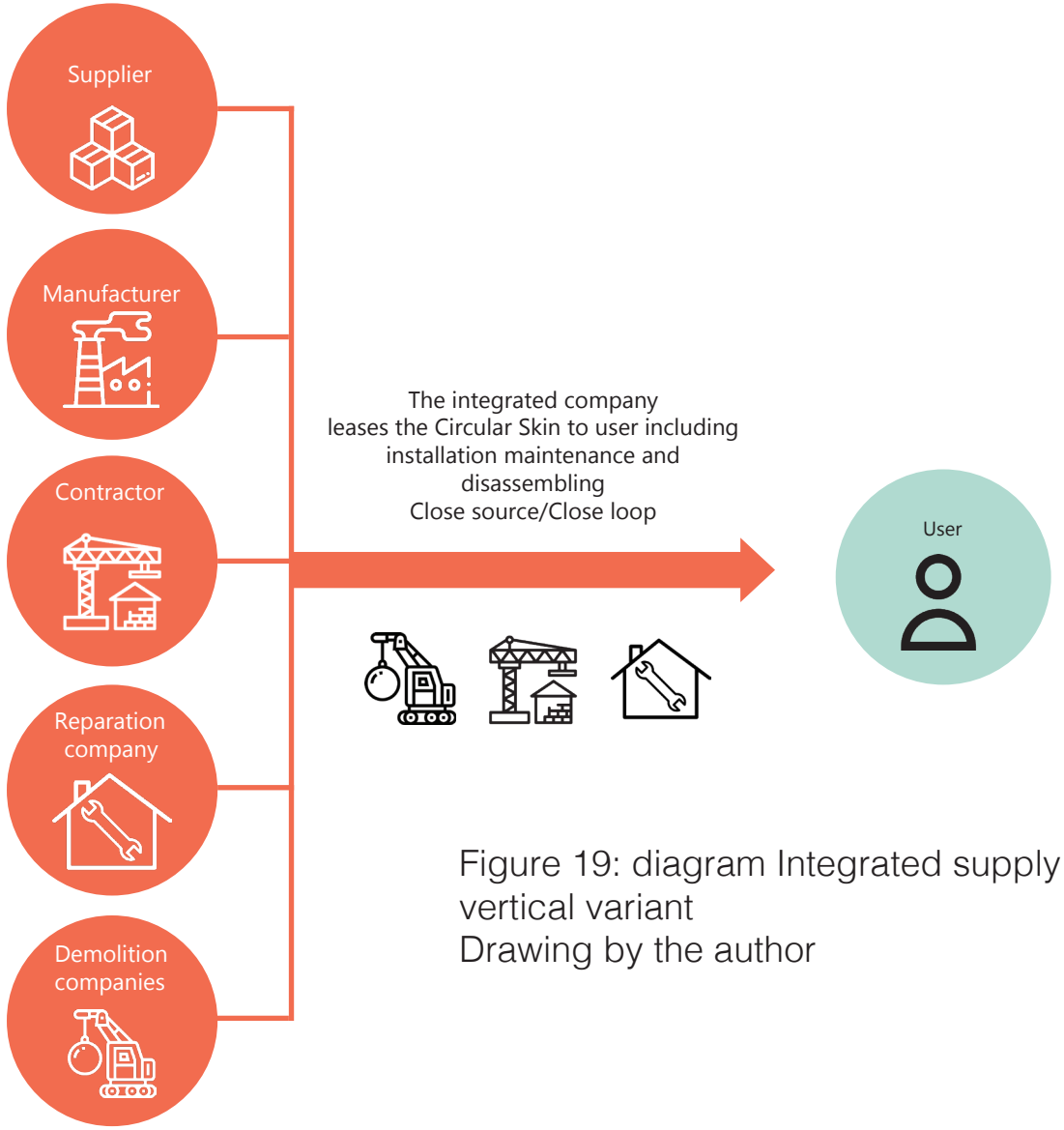

Figure 19: diagram Integrated supply chain on vertical variant
Drawing by the author

Who?	Manufacturers
What?	Will be responsible for installation, maintenance and disassemble
Why?	Experienced teams will be more productive working with Circular Skin
Where?	Maintenance and demolition sectors
When?	After the user buys the product

Who?	Manufacturers
What?	Reuse and remanufacture the components of the Circular Skin for producing other facades
Why?	Increase circularity, minimise waste and limit resource consumption
Where?	Remanufacture phase
When?	The end of the life product

Who?	Manufacturers
What?	Will develop circular supplying centres
Why?	To reintegrate the product in the circular cycle
Where?	Maintenance and demolition sectors
When?	After the user buys the product

Who?	User
What?	Leases the Circular Skin from the manufacturer
Why?	Reduce the initial investment, paying just for the service
Where?	Construction sectors
When?	Exploitation phase

VII. The simulation phase

The possibilities and limitations were determined during the simulation phase through a series of interviews. The researcher has interviewed various stakeholders related to Circular Skin or professionals who work in the construction industry.

The interviews were semi-structured, representing an open discussion, but uses a preestablished guide to cover several topics. The questions were open to intensify the dynamics of the talk and encourage the interviewee to express freely and inspire new ideas to be brought up. In the beginning, the interviewer presented the interview methodology and the framework of chain elements (figure 14) as an inspiration for determining possibilities and limitations.

The interviews had two parts:

- Determination of possibilities and limitations for each variant
- Ratings: environmentally friendly, resource efficiency and economic feasibility

The interviews approached the topic of the circular supply chain in the building renovation industry. The interviews included questions related to the stakeholders' possibilities and market challenges associated with the implementation of circular supply chain practices in the insulation materials industry.

The interviewee was asked to analyse every variant from two different perspectives: the possibilities and limitations of implementing the respective variant and evaluating the proposed supply chain. An essential tool for determining the possibilities and limitations of every variant is the framework of chain elements. The interviewees were clearly instructed that the categories from the framework are used as a suggestion to respond with different possibilities and limitations, and there is no obligation to mention one possibility or limitation for each category. Further, the connection between the interviewee's answers and literature results for each category is presented in the simulation phase, correlating the knowledge from analysis with synthesis and simulation.

The ratings are used to assess each variant in three directions for each variant: environmentally, resource-efficiency and economical feasibility. Every rating issue is followed by the question "why?" for stimulating the interviewee to offer more explanations.

Figure 20: Rating variant
Drawing by the author

List of interviewees:

Name	Position	Company	Relevance for research
Feike Laane	Architect	Villanova	Technical input
Bas Kalshoven	Implementation Manager	Ymere	Housing association viewpoint
Razvan Bobeica	Cost Manager	Vitalis (Romania)	Cost differences between variants
Stefan Cantu	Site manager	TerraConstruct (Romania)	Analysis over assembling, disassembling and maintenance
Valentin Raducanu	Project Manager	Masterbuild (Romania)	Analysis over the supply chain from economical, logistical viewpoint
Maaz Khan	Product Designer	Eevee	Analysis of the variants as a product manufacturer

The transcripts of the interviews can be found in the Appendixes C, D, E, F, G, H

1. User oriented variant

Possibilities: During the interviews, the user-oriented variant's primary possibility is the implementation process because it is similar to the current construction supply chain. Furthermore, as a product owner, the user has the freedom to resell the facade's components at his/her convenience; This aspect was noticed by the Housing association manager and the Cost manager, underlining the idea that this variant encourages the free market and guarantees the rights of the customer. The Project manager interviewed remarked that the User-oriented variant presents limited risks and responsibilities for the manufacturer because it follows the current linear economic model where the market risks are partially known. The interviewer assessed that the manufacturer's business model could be easily formulated based on product sellings. Another interviewer, the Site manager, considered that this variant is suitable for the individual clients who want to assemble it by themselves, similar to the Ikea model, where the client follows the instructions and install the furniture. An engaging Cost manager's initiative of stimulating the market to become circular is the investment of governmental or European funds in private SH collectors to grow their business. European Union incentivises small businesses, especially in the sustainability area like the second-hand material collectors, trying to reduce the carbon footprint. The Manufacturer thought that these multiple processes represent the possibility of developing local jobs in collecting, second-hand, and remanufacturing, encouraging the local economy and creating sustainable processes. The Site manager considered that the material passport and eco-labelling could also be used as marketing strategies to determine the user to return the facade through the SH collectors. In this way, the eco-label could have a double effect: increasing the sellings and encouraging the product return.

Limitations: Three interviewees (Housing association manager, Project manager and Manufacturer) remarked that the main limitation is generated by how the user is managing the materials after disassembling. During the interviews, this variant was considered the least circular variant because, according to the Architect, it does not incentivise the user to disassemble and resell the components. Furthermore, the Architect and Housing association manager considered that human behaviour is a fluctuating variable of this variant, having a major impact on the return process. The problem is generated by how the people are using and managing the components after disassembling, the circularity being entirely dependent on the user.

Another limitation determined by the Architect might be that the client has to pay for the material passport and possibly transport and return. The material passport is an extra service that will determine the increase of the facade's price paid by future clients. Moreover, according to the Site manager, different unspecialised contractors will operate the facade in different phases could damage the components, and the manufacturer

or the SH collectors might reject many damaged parts. Besides, the return process is still uncertain because the user has to pay to transport the components to the collecting centre after the end of the facade's lifespan. Moreover, the Project manager underlined a critical point regarding the uncertainty of the potential buyers of the components. SH collector might not be interested in purchasing the components without having established a business relationship with the manufacturer. The Cost manager determined another reason of irritation for the user: several payments for various services like product price, installation, dismantling and maintenance.

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Partners						
This variant presents limited risks for the manufacturer					✓	
The source of materials						
The variant does not incentivise the user to disassemble and resell the component	✗					
The manufacturer should take into consideration another source of materials						✓
Manufacturing						
This variant represents limited risk and responsibility for manufacturer					✓	
Unspecialised contractors will operate the facade in different phases and could damage the components				✗		
Transportation						
The user will be happy to pay for the transport of the components.				✗		
Return flow						
The problem is generated by how the user is managing the materials after disassembling.		✗			✗	✗

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Uncertainty about potential buyers of the components.					✗	
Material passport and eco-labelling might determine the user to return the products				✓		
Economic feasibility						
This variant is similar to the current economical model	✓	✓	✓		✓	✓
The market risks are easily predictable					✓	
The multiple processes represent the possibility of developing local jobs						✓
The user has to pay for the product price and different services like installation, dismantling and maintenance.			✗			
Product design						
Client has to pay for the material passport (increased costs)	✗					
Many components might be damaged or unusable for the remanufacturing process.						✗
Regulation						
Government could invest in SH collectors, maybe by using European Funds			✓			

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
User's behaviour						
The user has the freedom to resell the facade's components at his/her convenience		✓	✓			
Human behaviour is considered to be the fluctuating variable of this variant.	✗	✗				
This variant is suitable for the individual clients who want to assemble it by themselves.				✓		

Ratings:

This variant scored unsatisfactory ratings in the environmentally friendly and resource-efficient categories. The environment category and resource efficiency were seen as mutually dependent on one another. This variant does not present a perspective of recovering the facade's components. The return process is strictly related to the user's behaviour. This fact might determine the loss of materials and the necessity of producing new components with primary raw material.

The resource efficiency is affected by the damages produced by different contractors, operating the facade, and the uncertainty regarding the return of components. On the other side, this variant obtained excellent ratings in the economic feasibility ratings because the economical implementation is similar to the vast majority of the construction products.

Name	*Rate environmentally friendly*	*Rate resource efficiency*	*Rate economical feasibility*
Architect	**2.5.**	**2.5.**	**5**
Housing association manager	**2**	**2**	**5**
Cost Manger	**3**	**3**	**5**
Site Manager	**3**	**1**	**5**
Project Manager	**1**	**1**	**5**
Manufacturer	**2**	**2**	**4**

2. Sell and buyback variant

Possibilities: The interviewees considered unanimously that Sell and Buyback variant sustains better circularity and stimulates the user to reduce the waste of materials. According to four interviewees, after the buyback, the manufacturer has two options: offer a discount for purchasing a new facade or a direct financial incentive. The Project manager supposed that a significant possibility for the manufacturer is the procurement of secondary materials at affordable charges through the buyback programme. Furthermore, the Architect considered it helpful that the manufacturer starts analysing the disassembling and returning processes, and it could lead to the development of new innovative techniques. Also, the Manufacturer mentioned that the buyback represents a reason for the connection between stakeholders. Any contact is beneficial because it could generate feedback, which can help the development of the variant. The Architect appreciated that the user's risk is limited because in case of a potential bankruptcy of the manufacturer, the user can still sell the components (similar situation with the User-oriented variant). Moreover, the Project manager mentioned that the EU encourages companies to become circular and sustainable. The only practical way to achieve this ambitious goal is to incentivise businesses using European funds or tax reduction. Lastly, the Housing association manager conditioned this variant's success of how the manufacturer explains it to the user.

Limitations: According to the Site manager, the buyback idea will incentivise the user to return, but the components' future value will be reduced. The main components of the Circular Skin (the insulation, the timber frame and the wood panel) might not be very valuable after several years because of the damage. Many interviewees found it challenging to determine the facade's future value after a more extended period of time. Another limitation remarked by three interviewees (the Architect, the Housing association manager and the Cost Manager) is represented by the necessity of trust or faith in the economy because the buyback will not be possible in case of the manufacturer's bankruptcy. The bankruptcy will irremediably affect the reintegration of the product in the loops. Furthermore, the Architect and the Cost manager also marked the stakeholders' necessity to trust that the manufacturer will honour the buyback agreement. The manufacturer will also have increased operational costs with the collecting and sorting centre for all the components according to Maaz Khan (Manufacturer). The manufacturer is responsible for dismantling the facade and transport back to the manufacturing point. These actions might increase the price of the facade. Moreover, the Project manager considered that the manufacturer might encounter difficulties in predicting and planning the flow of materials coming from buyback return.Two interviewees discussed about possible limitations regarding the manufacturing flow. The manufacturer will face multiple difficulties in processes like sorting and

repairing the damaged components because of negligent dissasembling. Furthermore, the manufacturer might encounter difficulties in predicting and planning the flow of materials coming from buyback return. Lastly, the Manufacturer believed that the buyback process could be irritating and might determine the user to throw the components away.

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Partners						
The necessity of trust in the manufacturer.	✗		✗			
This variant offers a reason for the connection between stakeholders, the buyback.						✓
User's risk is limited.	✓					
The source of materials						
Manufacturer can procure secondary materials at cheap charges.					✓	
Manufacturing						
Difficulties for manufacturer in sorting and repairing (the components might be damaged).						✗
The manufacturer might encounter difficulties in predicting and planning the flow of materials coming from buyback return.					✗	
Transportation						
The transportation costs could increase because the components should be collected and transported from the user location to the manufacturing centre.						✗

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Return flow						
The buyback will not be possible in case of the manufacturer's bankruptcy.	✗	✗	✗			
Economic feasibility						
It is challenging to determine the facade's future value after an extended period of time.			✗			
The manufacturer could offer a discount for purchasing a new facade to incentivise the user or to offer a direct financial incentive.	✓		✓	✓	✓	
The transport back to the manufacturer is questionable because it might increase the price of the facade.						✗
The manufacturer will also have increased operational costs with the collecting and sorting centre for all the components.					✗	
Product design						
The components of the Circular Skin might not be very valuable after several years.				✗		
Manufacturer starts analysing the disassembling and returning processes. Maybe new techniques will be developed.	✓					

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Regulation						
The EU encourages economic entities to develop their activities to become circular and sustainable.					✓	
User's behaviour						
The buyback process could be irritating and might determine the user to throw the components away.						✗
This variant is reasonably easy to achieve because it is possible to explain it to the user.		✓				

Ratings: Sell and buyback variant registered average grades around 3 stars in all three categories with few exceptions (2 and 4 stars). This variant improves the environment and resource efficiency part, but it lowers the economic feasibility because of the buyback. The environment is better protected in this variant because the manufacturer incentivises the user to return the components, limiting the waste. Resource efficiency is affected by a multitude of contractors involved in the construction process. The economic feasibility is decreased because of the uncertainty regarding the payment of buyback and the facade's future value.

Name	*Rate environmentally friendly*	*Rate resource efficiency*	*Rate economical feasibility*
Architect	**3**	**3**	**4**
Housing association manager	**3**	**3**	**4**
Cost Manger	**4**	**3**	**3**
Site Manager	**4**	**3**	**4**
Project Manager	**3**	**3**	**3**
Manufacturer	**3**	**3**	**2**

3. Sell and buyback without contractor variant

Possibilities: The interviewees understood that the only difference between this variant and the previous one is that the manufacturer is performing the installation of the facade. According to the Architect and Housing association manager, the efficiency of assembling and disassembling the facade could represent an incentive for the manufacturer to improve it. The manufacturer's involvement in the installation process could be proper for the supply chain for decompressing the procedures for the user. The Cost manager and the Project manager considered that the user's risk is lowered because the manufacturer will be responsible for assembling the Circular Skin. Furthermore, the Site manager appreciated the constructive process's linearity because only one stakeholder is involved in building, assembling and disassembling the Circular Skin. This change will not increase the manufacturer's expenses considerably because the construction and transportation departments also exist in the previous variant. Two other interviewees (the Cost manager and the Manufacturer) considered that the manufacturer has the possibility to install the Circular Skin skillfully without damaging the product. The limit of the damages preserve the components and facilitate their reuse after the return.

Limitations: However, Maaz Khan (the Manufacturer) and the Cost manager considered that the installation of the facade is an additional service, which will increase the price of the Circular Skin and raises the risk for the manufacturer. A significant risk for the manufacturer is the foresight of expenses due to the buyback payments, affecting directing manufacturer's income. The Architect thought that the open-source aspect of the supply chain represents the limitation, multiple interviewees considering that the manufacturer should maintain the facade. Also, he explained that parties might start pointing to each other if something is going wrong. In the construction industry, subcontractors point a lot to each other. Moreover, this transfer of activities significantly enlarges the demanded dimension of the manufacturer company, according to the Project manager. Another limitation of this variant defined by the Architect is that the user might be tempted to shop for the lowest price between different companies, neglecting the quality of the services. Ultimately, the Cost manager described that a deposit could represent a possibility and a limitation because the refund problem is still uncertain.

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Partners						
If something is going wrong, parties might start pointing to each other.	✗					
The manufacturer's involvement in the installation process could decompress the procedures for the user.			✓		✓	
This variant transfers the risk from the user to the manufacturer.			✓		✓	
The source of materials						
The installation performed by the manufacturer can limit the damages.			✓			✓
Manufacturing						
This transfer of activities significantly enlarges the demanded dimension of the manufacturer company.					✗	
Transportation						
The installation will not increase the manufacturer's expenses considerably.				✓		
Return flow						
Qualified workers do the work, allowing the reuse of the components.			✓			✓

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Economic feasibility						
This variant presents higher costs of the facade for the user						✗
A significant risk for the manufacturer is the foresight of expenses due to the buyback payments, affecting directing manufacturer's income.						✗
The installation of the facade is an additional service, which will increase the price of the Circular Skin.			✗			
A deposit could represent a possibility but also a limitation because the problem of refund is still uncertain.			✗ ✓			
Product design						
Manufacturer would improve the facade's installation and the whole construction process.	✓	✓				
The maintenance/reparation process is performed by an external contractor	✗					
The constructive process's linearity might be helpful because only one stakeholder is involved in building, assembling and disassembling the Circular Skin.				✓		

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Regulation						
Incentivise businesses using European funds or tax reduction.						
User's behaviour						
The user might be tempted to shop for the lowest price between different companies, neglecting the quality of the services.						

Ratings: The integration of the installation process in the manufacturer's services was considered helpful for resource efficiency and economic feasibility. Furthermore, the interviewees appreciated that the manufacturer performs both installation and disassembling. The facade is operated in the essential phases of the construction by only one party, keeping components undamaged. The Circular Skin's economic implementation is straightforward because the user will have all services included in the facade's price.

Name	*Rate environmentally friendly*	*Rate resource efficiency*	*Rate economical feasibility*
Architect	**3.5**	**3**	**4.5**
Housing association manager	**3**	**3.5**	**4.5**
Cost Manger	**4**	**5**	**4**
Site Manager	**3**	**4**	**4**
Project Manager	**3**	**3**	**2**
Manufacturer	**3**	**4**	**3**

4. Product as a service variant

Possibilities: During the interviews, it was concluded that the waste of this variant is minimal, and the circularity is unquestionably achieved. In terms of attracting new clients, four interviewees (Architect, Housing association manager, Project manager and Manufacturer) considered that the Product as a service variant could be attractive for housing corporations because of the lack of spending much money in the early phases. Another possibility of this variant identified by the Site manager is the manufacturer's motivation to design an efficient and easy facade to assemble, disassemble, and maintain. The user can later ask to replace the Circular Skin with another one, which is helpful because the facade could be updated with the latest technologies. Moreover, in residential housing, the aesthetical changes could be used as a design improvement and a marketing strategy. Further, the Cost manager considered that companies have strict budgets and, in this variant, the prediction of costs over time is easy. The manufacturer has the possibility to register higher revenues for the long term due to the periodic leasing fees.

Limitations: However, several interviewees consider this variant not indicated for an individual client for a long-term contract because the costs are definitely higher. The main limitation of this variant determined by five interviewees is the financial constraint of the large investment for the manufacturer. Without significant investment, the manufacturer cannot start this business. According to the Cost manager, the future fluctuation of the leasing fees might be problematic for the users due to inflation or currency depreciation. Besides, the Project manager believed that not having the product's ownership might determine the user to have abusive behaviour: negligence, vandalism or avoidable accidents. The Cost manager assumed that a technical solution for a modular facade like this might be more expensive than a fixed facade, for example, the first variant when the manufacturer did not have the certainty of recovering the facade. Furthermore, the Manufacterer considered that the flow of used components is hard to be predicted because the user can terminate the contract earlier than the initial prediction or ask for extensions.

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Partners						
There is an opportunity for the user to start a project without investing considerably.	✓	✓	✓			
The variant not indicated for an individual client for a long-term contract because the costs are definitely higher.				✗		
This variant could be attractive for housing corporations because of the lack of spending much money in the early phases.	✓	✓			✓	✓
The source of materials						
The manufacturer is motivated to recover the components						✓
Manufacturing						
The user can ask later to replace the facade with another one.				✗		
Transportation						
Circular Skin should be transported from a manufacturing centre towards an end-of-use location and backwards to the manufacturing centre without extra costs compared to previous variants.				✗		
Return flow						
The flow of used components is hard to be predicted.						✗

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Economic feasibility						
The manufacturer has the possibility to register higher revenues for the long term.			✓			
It requires a lot of money from the manufacturer for the initial investment	✗	✗	✗	✗		✗
The leasing fees might have fluctuations during the time			✗			
The business plan of the housing corporation could be affected by a bankrupt of the manufacturer.	✗					
Product design						
Manufacturer is motivated to improve the design,				✓		
The technical solution for a modular facade might be more expensive than a fixed facade.			✗			
Regulation						
Incentivise businesses using European funds or tax reduction.					✓	
User's behaviour						
Not having the product's ownership might determine the user to have abusive behaviour: negligence, vandalism or avoidable accidents.					✗	

Ratings: Product as a service variant presents predominantly good ratings in the environmental friendly and resource efficiency. This variant is environmentally adjusted for avoiding the loss of materials by returning precisely the components back to the product owner (manufacturer). The resource efficiency is improved by using better materials to last a long period of time, reducing, in the end, the material consumption. The manufacturer, who is is motivated to minimise the waste of components. However, economical implementation was thought to be challenging because of the necessity of a significant initial investment from the manufacturer. The economic feasibility is difficult because the construction sector is not used with the leasing process. Furthermore, the companies will not be very enthusiastic about investing in developing a product, which will return the investment after a long time.

Name	*Rate environmentally friendly*	*Rate resource efficiency*	*Rate economical feasibility*
Architect	**4**	**4.5**	**3**
Housing association manager	**3**	**5**	**2**
Cost Manger	**5**	**4**	**4**
Site Manager	**5**	**5**	**3**
Project Manager	**3**	**3**	**3**
Manufacturer	**4**	**4**	**3**

5. Vertical supply chain integration variant

Possibilities: The most visible possibility of Vertical supply chain integration is the guarantee of the complete circularity of Circular Skin because the manufacturer will recover all the facades' components and reuse them according to the majority of interviewees. According to the Cost manager and Project manager, the improvement of the material flow will lower the production cost and create a secondary material source. Furthermore, the advantages are clear management practices by having all tasks and responsibilities established. The manufacturer proposed that regulation could be modified for these particular companies to support them: for instance, tax reduction for limiting the carbon footprint. This variant is considered ideal for the user, especially a housing corporation, because it is not necessary to invest massively in the early phases of the project. Moreover, two interviewees (the Housing association manager and the Site manager) considered that the user is exempt from any risks. According to the Manufacturer, the integration of different branches in the same company would dynamise the processes and reduce the waiting time with procurement. For example, he thought that the transport distances could be reduced from supplier to manufacturing point and further to the end-use location, decreasing the carbon footprint.

Limitations: Almost all interviewees believed that the main limitation of this variant is that it is applicable only to existing giant corporations. Only these companies can afford to invest enormously in developing their company on vertical for having suppliers, contractors, and manufacturers' centres integrated. Another fundamental limitation viewed by the Site manager and the Architect is to sustain all these departments of the company financially for a long time. The Cost manager and the Manufacturer expected that the investment should be recovered from the lease fees, conducting to higher costs for the user. Usually, these gigantic corporations are focused on consumer products, final goods like Apple and Microsoft, not leasing performances.

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Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Partners						
Applicable only for existing giant corporations	✗	✗	✗	✗		✗
The user is exempt from any risks in this variant.		✓		✓		
This variant would attract individual users because they will have to pay for services and not for the product itself.		✗			✗	
The source of materials						
The manufacturer will recover all the facades' components and reuse them.				✓	✓	
Manufacturing						
Sustaining financially all departments of the company for a long time could be expensive	✗			✗		
The integration of different branches in the same company would dynamise the processes and reduce the waiting time with procurement.						✓
Transportation						
The transport distances could be reduced from supplier to manufacturing point and further to the end-use location.						✓

Circumstance	Architect	Housing association manager	Cost Manger	Site Manager	Project Manager	Manufacturer
Return flow						
This variant can ensure the Circular Skin's full circularity of components.	✓	✓	✓	✓	✓	
The improvement of the material flow will lower the production cost and create secondary material source.			✓		✓	
Economic feasibility						
The manufacturer needs much money to invest	✗	✗	✗			✗
The investment should be recovered from the lease fees, conducting to higher costs for the user			✗			✗
Product design						
The manufacturer company can promote innovation or develop a very circular design.	✓					✓
Regulation						
The tax regulation could be modified for circular companies to support them.						✓
User's behaviour						
The company should promote its circular and sustainable design for marketing purposes, generating user's awarness.			✓			

Ratings This variant was definitely rated the most performant one in the first two categories because all processes (procurement, manufacturing and construction) are integrated, and the loss of material is almost zero. The manufacturer, the product owner, is directly interested in recovering the components.
However, the economic feasibility of this variant was perceived differently by the interviewees. Two of them awarded maximum ratings, motivating that for a giant corporation (manufacturer), the chances of a possible bankruptcy are small. Even if a corporation has a delicate financial situation, the governments will help them with loans for avoiding bankruptcy. The other interviewees rated with approximately 3 stars for this variant, explaining that the applicability is reduced because only large corporations can adopt and adapt to it. Compared to the previous variant, the current one is even more restricted because the initial investment is more significant.

In *conclusion*, the possibilities and limitations were established during the simulation phase through interviews, representing an important step for answering the main research question. In the next phase, the possibilities and limitations will be evaluated and corroborated with the literature review and the categories presented in the framework of chain elements.

Name	*Rate environmentally friendly*	*Rate resource efficiency*	*Rate economical feasibility*
Feike Laane	**4**	**5**	**3.5**
Bas Kalshoven	**3**	**5**	**3**
Razvan Bobeica	**5**	**5**	**3**
Stefan Cantu	**5**	**5**	**5**
Valentin Raducanu	**5**	**5**	**5**
Maaz Khan	**5**	**5**	**2**

VIII. The evaluation phase

During the synthesis phase, five circular variants of the supply chain for the Circular Skin were produced. Furthermore, during the simulation, I extracted from the interviews the possibilities and limitations of implementing the variants. Now, during the evaluation phase, the interviewee's answer will be examined and corroborated with the literature review findings following the structure of the framework of chain elements. Moreover, I will present a conclusion of simulation and evaluation based on three different relations.

1. Evaluation of the variants corroborated with the literature review

The corroboration between the literature review and the answer from the simulation is a fundamental step for my research. I want to mention from the beginning that this process is cherry-picking and subjective. I correlate for each category for every variant the most suitable scientific possibility or limitation with interviewees answer. This process is valuable because it presents overpasses and intersections between the general cases from the scientific literature with the practical views of the construction specialists over our product, the Circular Skin. I consider that the place of this sub-chapter should be in the evaluation phase it connects two main phases of my research: analysis and simulation. The outcomes from the literature review are evaluated using the weight of the professionals' answers regarding Circular Skin.

1.1 User oriented

Partners: The vast majority of the interviews considered that the transition from linearity to supply chain's circularity is uncertain in the proposed variants (except User-oriented variant). The User-oriented variant is excepted of any uncertainty because the variant is similar to the current construction supply.

The source of materials: Two interviewees (Maaz Khan and Razvan Bobeica) considered the manufacturer should reconsider the source of the materials in the future. The reuse of the facade's components reduces materials' loss and limits the primary raw material's consumption.

Manufacturing: Maaz Khan underlined the idea that this variant encompasses multiple processes, determining local jobs and regional economic development.

Transportation: The costs of transportation are not included

User-oriented

External factors that will influence the supply chain

Economical feasibility

McKinsey & Company developed an economical recovery and reuse model for plastics to design process flows.
Gao et al., 2020

Regulation

Current legislation on circular supply chain encourages more recycling rather than reuse or repair.
Kissling et al. 2013

Direct components of the supply chain

Transportation

The transportation costs increase because the components should be collected and transported from a manufacturing center towards an end-of-use location and backwards after the end of the product's lifespan.
Bakker et al. 2014

Partners

The process of shifting from a linear to a circular supply chain is uncertain.
Gupta, 2018

Supply chain management

Return flow

Eco-labelling and sustainability certification could influence the behaviour of the client to return their product.
Masi et al., 2017

Source of materials

CE encourages a balanced usage between the finite reserve and renewable raw materials.
EMF, 2015

Re/Manufacturing

Stakeholders can use the recycling of residual material inside Europe, creating jobs locally.
EMF, 2015

Product design

Long lasting design might fail to respond to fashion changes, resulting in demand decrease.
Linder and Williander, 2017

User's behaviour

Customers' concerns are more related to the price and performance of the product than the environmental benefits of its circular supply chain.
Nasir et al., 2016

Figure 21:Evaluation User-oriented variant
Drawing by the author

in the price of the facade, which represents a possibility of becoming more attractive for potential clients. However, one of the interviewees identified a limitation in the return process because the user will be happy to pay for the transport of the components.

Return flow: The interviewees perceived this variant as having the most critical deficiencies in the return process. However, Stefan Cantu considered that the material passport and eco-labelling are great instruments to determine the user to return the products.

Economic feasibility: The interviewees considered the User-oriented variant similar to the current economic model. McKinsey & company developed an economic recovery and reuse model for plastics to design process flows, which can be used in this variant.

Productdesign: Feike Laane supposed that the manufacturer has to produce durable, long-lasting components to resist the different construction and transportation processes. After several years, the design might not respond suitably to the new fashion changes.

Regulation: Razvan Bobeica considered the authorities to endorse the user or SH collector to recover the components, accessing governmental or European funds. In this way, the components are primarily reused and not recycled.

User's behaviour: Valentin Raducanu affirmed that the user might decide upon a product by using the cheapest price criteria, neglecting the sustainable aspects. Furthermore, the manufacturer will concentrate on producing Circular Skin as cheap as possible instead of reducing the environmental impact and material loss.

1.2 Sell and buyback variant

Partners: Bas Kalshoven believed the success of this variant is strictly dependent on how the manufacturer will explain to the user how the product buyback works. If both main stakeholders, user and manufacturer, will share the same circular vision, the transition towards a circular supply chain will be achieved.

The source of materials: Stefan Cantu questioned the quality and future value of components over the years. The insulation, the timber frame and the wood panel, might not be extremely valuable after several years, and this uncertainty could affect the circular supply chain.

Manufacturing: Valentin Raducanu supposed the manufacturer might encounter difficulties predicting and planning the flow of materials coming from buyback return. This uncertainty might influence the production of new Circular Skin facades, affecting the relationship between the

Sell and buy back

External factors that will influence the supply chain

Economical feasibility

The efficiency of processing existing used materials, like reuse, remanufacture, refurbish or recycle, has been increasing constantly overtime. The change in the consumption culture of sharing economy, like product reuse, is beneficial for stakeholders involved in circular economy.
Korhonen et al., 2018

Regulation

Possible financial incentives are incorporated in the current taxation system.
Al Zaabi et al., 2013

Direct components of the supply chain

Transportation

In a circular supply chain, the transportation costs increase because the components should be collected and transported from a manufacturing centre towards an end-of-use location and backwards after the end of the product's lifespan.
Bakker et al. 2014

Source of materials

The uncertain quality of the secondary raw materials is an obstacle, (for example: plastics).
EU Circular Economy Action Plan, 2015

Supply chain management

Partners

Transition towards a circular supply chain is facilitated by the existence of a shared vision of stakeholders: common approach and responsibilities .
Farla et al., 2012

Re/Manufacturing

The stakeholder's concerns are focussed on uncertainties represented by the planning capacity for renovation activities, such as remanufacturing.
Linder and Williander, 2017

Return flow

Efficient public communication could increase the awareness level of population for determining them to with circular principle of returning the product.
Lieder et al., 2018

Product design

The renovation or restoration difficulty increases proportionally with the product complexity.
Despeisse et al., 2017

User's behaviour

Customers' concerns are more related to the price and performance of the product than the environmental benefits of its circular supply chain.
Nasir et al., 2016

figure 22: Evaluation Sell and buyback variant
Drawing by the author

manufacturer and new users.

Transportation: In this variant, the manufacturer will ensure transportation for returning the components. Maaz Khan explained that transportation costs could increase because the components should be collected and transported from the user location to the manufacturing centre.

Return flow: As presented in the Partners category, Bas Kalshoven conditioned the return of the components to the relationship between stakeholders. The manufacturer has to precisely explain how the buyback works, creating a partnership based on trust with the user.

Economic feasibility: The economic feasibility was received with scepticism by the majority of stakeholders, but all of them believed that the current economic model might change in the future. The buyback system presented in this variant is not a usual practice in the construction sector, but it might become over time.

Product design: Stefan Cantu considered that the open-source aspect of the supply chain represents the limitation because the product has its own particularity. The manufacturer should perform the installation and restoration for avoiding to damage the facade.

Regulation: For the Sell and buyback variant, Valentin Raducanu proposed an innovative system, which is advantageous for the user. The governmental authorities should support the trust between manufacturer and user by guaranteeing the buyback payment to the user, in case of manufacturer's bacnkrutpcy.

User's behaviour: Similar to the first variant, the price might be used as the buying decision principle criteria, neglecting the sustainable features.
The manufacturer will try to produce Circular Skin as cheap as possible instead of reducing the environmental impact and material loss.

1.3 Sell and buyback without a contractor

Partners suppliers: The previous variant was considerably criticised for the open-source installation, the interviewees considering that the manufacturer should be responsible for the whole construction process. Stefan Cantu considered that Sell and buyback without contractor variant repairs this situation, appreciating the constructive process's linearity because only one stakeholder is involved in building, assembling and disassembling the Circular Skin.

The source of materials: Feike Laane believed that the manufacturer would improve the installation of the facade and the whole construction process. This variant supports sustainable cycles by preserving the components of the facade. The manufacturer might have the possibility to reuse the materials and develop a secondary source of materials.

Manufacturing: Valentin Raducanu thought that there is a significant

Sell and buy back without contractor

External factors that will influence the supply chain

Economical feasibility

The financial uncertainty due to lack of clearness in foresight the incomes is dangerous in a circular supply chain in the construction industry.
Adams et al., 2017

Regulation

EU Circular Economy Action Plan' s main goals is to develop an economy which preserve the value of products as long as possible and minimise waste.
European Commission, 2015

Direct components of the supply chain

Transportation

In a circular supply chain, the transportation costs increase because the components should be collected and transported from a manufacturing centre towards an end-of-use location and backwards after the end of the product's lifespan.
Bakker et al. 2014

Partners

The common approach of stakeholders demands a collaborative stand for determining the most sustainable practices.
Jackson et al., 2014

Supply chain management

Return flow

Stakeholders could use an financial incentive for the product take-back, such as the deposit-refund scheme, for decreasing the return uncertainty level.
Wojanowski et al., 2007

Source of materials

Encouraging sustainable cycles, not using toxic materials and tracking chemicals will promote recycling and developing uptake of secondary raw materials.
EU Circular Economy Action Plan, 2015

Re/Manufacturing

An analysis conducted to the conclusion that companies can make cost savings of 50% for remanufacturing compared with producing a new product.
EMF, 2015

Product design

The inner cycles presented in Butterfly Model (EMF, 2013) should be preferred over the large cycles Slowing the resource cycles, The waste should be diminished at every lifecycle The stakeholders should be focussed on reduce, reuse, recycle and recover resources.
Govindan et al., 2015

User's behaviour

Customers' concerns are more related to the price and performance of the product than the environmental benefits of its circular supply chain.
Nasir et al., 2016

Figure 23: Evaluation Sell and buyback without contractor variant
Drawing by the author

possibility for the manufacturer to procure secondary materials at affordable charges. The Ellen Macarthur Foundation analysis is relevant for this variant for presenting the possible cost savings.

Transportation: Stefan Cantu considered that the introduction of installation is not a significant change in terms of expenses because the transportation department (car fleet and specialised workforce) already exist in the previous variant. If the Circular Skin should be transported from a manufacturing centre towards an end-of-use location and backwards.

Return flow: Razvan Bobeica discussed a deposit-refund scheme, which was assessed as a possibility and a limitation because the refund is still uncertain.

Economic feasibility: Maaz Khan considered that the foresight of expenses due to the buyback payments represents a significant risk and might directly affect the manufacturer's income. This uncertainty could affect the company's financial situation, even resulting in bankruptcy and destroying the whole circular supply chain.

Product design: Bas Kalshoven supposed that the Sell and buyback without contractor variant would determine the manufacturer to optimise the design. The manufacturer is interested especially in dimishing the waste and recovering and reusing the resources.

Regulation: Valentin Raducanu discussed the European Union's ambitious plans to encourage the Circular Economy. He considered that the only practical way to achieve this ambitious goal is to incentivise businesses using European funds or tax reduction.

User's behaviour: The manufacturer produces Circular Skin according to the user's desires. Supposing the price is the buying decision principle criteria, neglecting the sustainable features, the manufacturer will try to produce Circular Skin as cheap as possible instead of reducing the environmental impact and material loss.

1.4 Product as a service variant

Partners suppliers: Bas Kalshoven considered that the possibilities of the Product as a service variant are enormous, but the way to get there is challenging. The relationship between manufacturer and housing corporation should be based on trust, and any lack of information should be avoided. The lack of information could deteriorate the business relationship and generate suspicion.

The source of materials: Razvan Bobeica admitted that the return process is secured in this variant because the manufacturer will recover the product back. Furthermore, the loss is minimal, and the components are reused because the manufacturer will remain the product owner.

Manufacturing: Stefan Cantu considered a modular technical solution for a modular facade to be

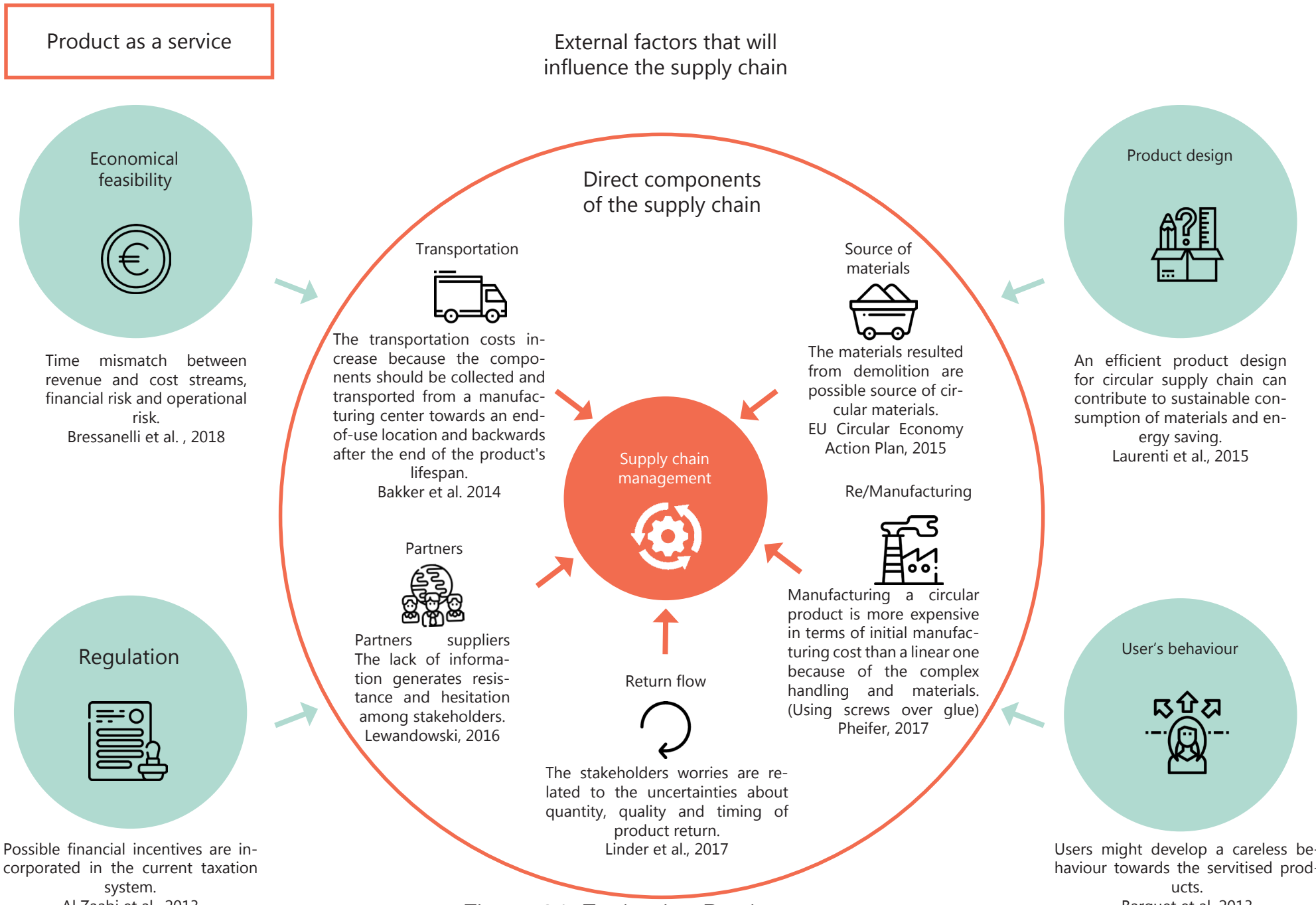

Figure 24: Evaluation Product as a service variant
Drawing by the author

more expensive than a rigid facade (using screws over glue). Having the certainty of recovering the facade, the manufacturer will improve the design for disassembling, and this costs can be recovered from the material reuse.

Transportation: Stefan Cantu thought about Sell and buyback without a contractor that the introduction of installation is not a significant change in terms of expenses because the transportation department (car fleet and specialised workforce) already exist in the previous variant. This reflection is applicable also for the Product as a service variant because Circular Skin should be transported from a manufacturing centre towards an end-of-use location and backwards to the manufacturing centre.

Return flow: Maaz Khan discussed that the return flow of used components is hard to be planned accurately because the user can terminate the contract earlier than the initial prediction or ask for extensions.

Economic feasibility: Razvan Bobeica widely discussed the time mismatch between revenue and initial investment. He considered that the manufacturer should be financially prepared to sustain the investment because it will be recovered slowly in time through the leasing fees.

Product design: The interviewees unanimously considered this variant truly circular, assessing it to be environmental friendly and resource-efficient. The conception of this variant around the manufacturer's product ownership ensures minimising waste and raw material saving.

Regulation: Following Valentin Raducanu's point of view from the previous variant, a practical way to achieve this ambitious goal is to incentivise businesses using European funds or tax reduction.

User's behaviour: Valentin Raducanu believed that not having the product's ownership might determine the user to have abusive behaviour: negligence, vandalism or avoidable accidents. The abusive behaviour of the owner might determine litigation and penalties, conducting to mistrust between stakeholders.

1.5 Vertical supply chain integration variant

Partners suppliers: Bas Kalshoven considered that the Vertical supply chain integration variant represents a massive possibility for both economy and environment. The resources of the manufacturer/contractor are enormous and could be directed for generating plus value through a circular economy, satisfy user's needs and protect the environment.

The source of materials: This variant scored remarkable ratings in the circular categories (environmental friendly and resource efficiency). The manufacturer is the product owner and is directly interested in minimising waste and securing the return process.

Manufacturing: Razvan Bobeica thought the company should promote its circular and sustainable design for marketing purposes. This action could have two positive effects: positive public perception of the manufacturer and the user's awareness of the importance of the circular economy.

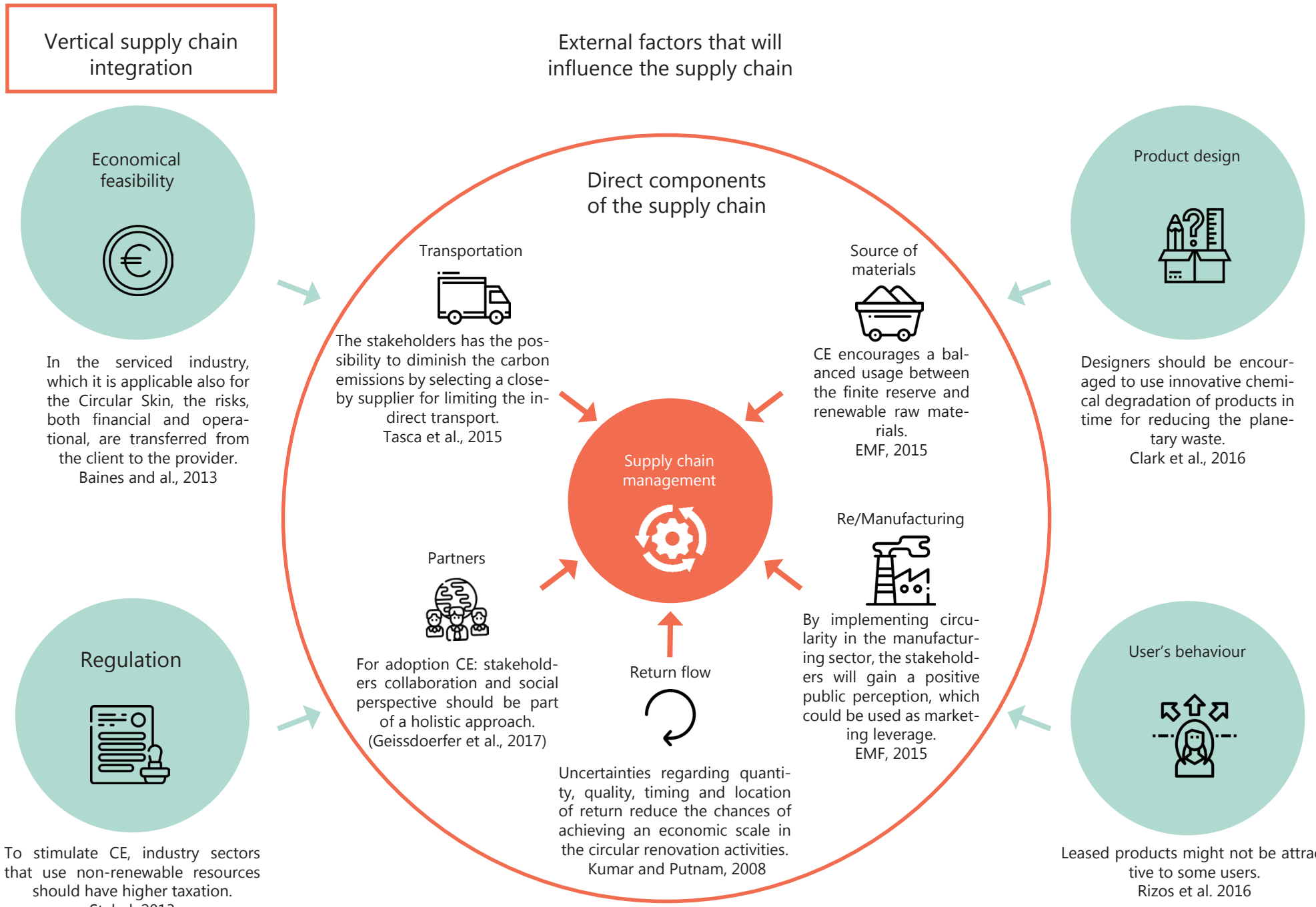

Figure 25: Evaluation Vertical supply chain integration
Drawing by the author

Transportation: Maaz Khan believed that the transport distances could be reduced from supplier to manufacturing point and further to the end-use location, decreasing the carbon footprint. The integration of different branches could determine the shortening of distances, especially between suppliers and producing factories because the manufacturer is interested in reducing the costs.

Return flow: Like other variants, the interviewees considered that the return flow of used components is difficult to be accurately planned because the user can decide to terminate the contract earlier than the initial prediction or ask for extensions.

Economic feasibility: Bas Kalshoven discussed that this variant is favourable for the user, while the manufacturer has to invest significantly in the early phases. Moreover, Stefan Cantu considered the user is exempt from any risks in this variant.

Product design: The Circular Skin should be a combination of the plug-and-play, reclaim and bio-skin variants. The technical design of Circular Skin was not analysed during the interviews, but all interviewees considered that this variant is the most protective of the environment. The vertical supply chain variant primarily focusses on reusing the components and reducing the waste because only one company owns the product, the manufacturing points and the suppliers. In this way, the process could be optimised and perfected.

Regulation: Maaz Khan supposed that authorities could modify the regulation for these particular companies to support them: for instance, tax reduction for limiting the carbon footprint.

User's behaviour: The construction industry is one of the most conservatory industries, where the resistance to change is robust. Valentin Raducanu showed doubt that this variant would attract individual users because they will have to pay for services and not for the product itself.

2. Conclusion to the simulation and evaluation

The simulation and evaluation are the final steps of the research. I consider that research answer to the main question and the secondary questions accurately. Furthermore, besides the answer I was seeking initially, there are three more points worth mentioning.

2.1 The relation between the type of user and variant

During the interviews, one topic unintentionally came into the conversation: which type of user is favoured according to different variants. The respondents identified a correlation between product ownership and the supposed type of user. The user-oriented variant, where the user is the product owner, was unanimously considered suitable for an individual client user. Nevertheless, the low ratings in terms of the user-oriented variant's circularity determined the interviewees to recommend alternatives: the Sell and

buyback or Sell and buyback without contractor variants. The individual projects do not require significant investment, and the user can afford to pay the price of the facade.
On the other side, the macro-level users, like housing corporations, would benefit from the leasing variants: Product as a service and Vertical supply chain integration. According to Bas Kalshoven, the housing corporations will not need to maintain or build the facades and can focus on their core business: renting accommodation. Paying directly for the service is an excellent feature of these circular variants, helping developers start projects without more significant investments and avoid bank finances and interest rates.

2.2 Relation between product ownership and circularity

The five variants have different types of ownership, loop, source, return process or payment. Based on the ratings, there is a direct link between ownership and circularity (environmental friendly and resource efficiency categories). The linkage is determined by the product owner's drive to recover the components.

In the diagram, there are two poles: closed and open. The closed pole symbolises that the manufacturer has full ownership of the product, including a closed-source and a closed-loop supply chain. On the other side, the open pole presents an open-source and open-loop supply chain where the user is the product owner.

According to the ratings, there is a direct link between the closed pole (Vertical supply chain integration and Product as a service variants) and excellent circular result. The interviewees perceived the variants where the manufacturer is the product owner as resource-efficient and environmental friendly because of recovering their own product.

On the other hand, user owner variants have inferior circular ratings (environmental friendly and resource efficiency) because human behaviour is considered a changeable variable, affecting the return process. The interviewees considered that in case the user is the owner will be not very determined to return the components to the manufacturer or the second-hand material collectors.

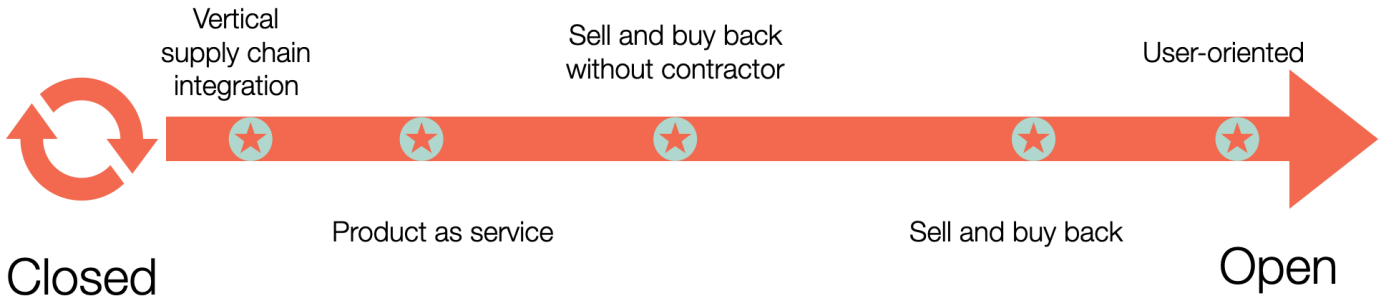

Figure 26: diagram Open/Closed pole
Drawing by the author

2.3 Relation between return process and economic feasibility

The five variants have three different payment types after the return process: selling (User-oriented), buyback (Sell and buyback and Sell and buyback without a contractor) and returning when the leasing contract is completed (Product as a service and Vertical supply chain integration).

The User-oriented variant is the only supply chain that follows the traditional approach of buying or selling a product. The user has a discretionary option to throw away the product or sell it to second-hand suppliers. The interviewees considered this variant easy to achieve economically because it is similar to the current supply chain. It is worth be mentioned that many interviewees conditioned the success of a variant and the way the manufacturer will explain to future clients. Genuinely, this variant is the simplest to be presented due to usual practice nowadays in the construction industry.

The buyback variants scored upper-intermediate ratings (3-4 stars). The interviewees mostly appreciated the return process, except the uncertainty regarding the future value of components. The economic feasibility is depreciated due to the uncertainty regarding the future value of the facade. Many interviewees were not convinced about the evaluation of the amount paid to the user for recovering the facade's components. Furthermore, the quality of the components at the end of the product lifespan was questioned.

The leasing variants registered modest ratings in the economic feasibility category because of the necessity of a significant investment in the project's early phase. However, two interviewees considered this variant remarkably economically feasible, explaining that it is designed for a corporation with minimum bankruptcy chances.

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IX. Validation of the data

To ensure that the outcomes are answering the research question and following the direction of the methodology, the author of the thesis created a validation procedure. The research findings were examined and validated by the two Construction Management and Engineering students who are completing their graduation thesis in different areas of the REHAB project. Denis Chiosea and Stefanos Voglis are knowledgeable about the following concepts: Circular Economic, the improvement of the current economic model in the construction sector, and different collaboration processes.

During the validation meeting, the researcher presented the methodology, the analysis, the simulation and the evaluation phases. The key asphects which were discussed are the problem statement, the methodology and the findings. Therefore, the author of the thesis asked five open questions which follow the next structure:

The WHAT: Is the subject mentioned really the subject of my problem definition?

Denis and Stefanos considered that the thesis explores and analyse different possibilities and limitation of organising circular supply chains for the Circular Skin. They recommended that the problem be narrowed specifically for Circular Skin and suggested avoiding giving a general solution for the whole circular economy matter.

The WHY: Is the problem for my research question really relevant, and does it add value to science and society?

Denis Chiotea thought that considering his experience in preparing literature reviews on the related topics of circular supply chain and circular co-creation, the research problem is really important because the literature lacks examples of the precise design of circular supply chains. Stefanos strengthened the idea of literature lacking in the circular supply chain area, arguing that there are many papers where the circular supply chain is mentioned but not explained with concrete examples.

The HOW: Do the research methodology really answer my research questions?

In Denis's opinion, the research methodology is suitable for answering the research questions because several variants were created and tested by actual people who work in the construction industry. During the simulation phase, the possibilities and limitations were identified and crossed, in the evaluation, with the literature review. However, Stefanos pointed out that these five variants are a limited number of answers, and the results could be broadened and further explored and explained.

The RESULT: Is the answer that resulted from my methodology research really the answer I was looking for?

The two students appreciated that the methodology research was applied correctly, generating possibilities and limitations for implementing the circular supply chains of Circular Skin, exactly what was asked for. The possibilities and limitations denote a precise answer to the main question of the research, but they considered there is also room for further study. The direct examination of the five circular supply chain variants was considered a reliable form to determine the possibilities and limitations, but it restricted the research to these five variants and possibly neglecting other solutions.

The WHAT ELSE: How would you have improved the findings/ research?

Stefanos Voglis noticed that the research is mainly focussed on circularity and not on the financial part. He suggested that it might be interesting to see how the costs fluctuate for every variant. Moreover, Denis Chiotea proposed a separation in the economic feasibility rating category in two: general economic feasibility of the integration in the construction market and the interviewee's economic perception about the feasibility for her/his specific company.

X. Discussion

The purpose of this graduation thesis was to fill the gap in the research area regarding the possibilities and limitations of implementing the Circular Skin components into a circular supply chain. The study results are the five variants of circular supply chains, especially the possibilities and limitations of each variant. However, it is worth mentioning that the research has several limitations.

The literature review is the foundation of my graduation thesis because I determine multiple possibilities and limitations, divided into nine principal categories, presented in the personal framework. The categories framework was extremely useful, not just during the analysis phase (literature review) but especially during the simulation and evaluation when interviewees assessed the circular variants using the framework as a tool. The Charette day was the connection day between the analysis and the synthesis phases, between what we already know and what you can create new. During the Charette, I presented my findings from the literature to the audience: the framework of chain elements (figure 14) alongside the possibilities and limitations and the existing circular supply chain models. I considered that the main tool used in creating my variants is the lessons learned from other circular supply chains (pag 38) because it connected directly other models to our new variants.

Therefore, an important deliverable of my thesis is represented by the five variants of the circular supply chain for the Circular Skin. These variants present different supply chain scenarios, variating the product owner (manufacturer, contractor or the user), open/close loop, open/close source, the return flow and the remanufacturing process.
Furthermore, my most notable graduation output is the classification and presentation of possibilities and limitations of implementing the Circular Skin in a Circular supply chain. I preferred to present the possibilities and limitations for every variant particularly, and not ordinarily for a general circular supply chain.

Personally, I consider that this report results met my expectations partially and answer the research questions accurately. The significance of the graduation thesis is represented by the five circular variants alongside their possibilities and limitations. During the literature review, I encountered difficulties finding certain circular supply chain models and not just related to the construction industry. I consider that for a future reader, my thesis represents a clear asset in understanding how works a circular supply chain in the construction renovation area. The most satisfying and unexpected result of my graduation process was the correlation between the literature review and the interviewees' answers in the evaluation phase, following my personal frameworks' circumstances.

As a first impression, I can state that my results correspond mostly with the literature, but it is more accurate to say that it supplements the existing knowledge on the subject of the circular supply chain. The

interviews provide a contribution from the professional perspective of the personalities who are actively involved in the construction process. For example, in the Sell and buyback variant, the stakeholder's concerns are determined by uncertainties regarding the planning for remanufacturing activities (Linder and Williander, 2017). One of the interviewees, Valentin Raducanu, consider that the manufacturer might struggle planning the flow of materials coming from buyback return. This uncertainty might influence the production of new Circular Skin facades. However, to be honest, I noticed that a part of the interviewees perceived these variants to be very theoretical, without having too many chances to be applied in the industry. For example, the leasing variants were considered to be almost a utopia because this is an ideal situation to lease the facade.

Nevertheless, several factors limit the generalizability of the results. One important factor is the limited number of variants of the circular supply chains. There could be many other supply chain variations with different solutions for open/closed source or open/closed-loop or another product owner. Nevertheless, it is important to mention that a higher number of variants will make harder the simulation process by increasing the duration of the interviews, which will discourage the interviewees from participating. I would like to mention that the limited number of interviewees, six, could have narrowed the simulation. I met difficulties in convincing people to join the simulation, and I would like to thank the six interviews who accepted to participate in my research: Feike, Bas, Razvan, Valentin, Stefan and Maaz. I considered that more interviews, from more diverse areas like an SH collecting company or a big Dutch construction contractor or a manufacturer that produces sustainable facades, would have positively impacted my thesis. Another notable lack of research is a reflective economic plan which can include detailed financial data about investment, costs and return. These reports might transform the supply chain variants into genuine business models.

The limitations enunciated above could lead to further research. Future studies should analyse at least one variant in detail, both economically and environmentally. I would like to see an imaginary simulation for one of the variants. I perceive this simulation divided in two directions: environment and business. In the environment part, I consider it helpful to see a calculation of CO2 emissions of the whole process: supply, manufacturing, transportation, construction, return and remanufacturing. Furthermore, possible investors will be interested in numbers: "how much?". Further research should include a financial plan, incorporating a forecast of the necessary investment, operating costs and possible revenues. Finally, during my research, I noticed that one particular category from the framework of the circumstances had drawn the interviewees' attention: user's behaviour. In an ideal society, where everybody is aware and caring for the environment, my thesis will be useless because the circularity would be completely achieved in any variant. However, how long we are not living in a utopia, I imagine that an

academic research, which explores and analyses the user's behaviour for different variants of the circular supply chain, is fascinating.

XI. Conclusion

This research aimed to identify the possibilities and limitations of stakeholders involved in the REHAB project in implementing the Circular Skin in a circular supply chain. Based on research through design methodology, it can be concluded that Circular Skin might be implemented in at least five ways following the variants of the circular supply chain. Each variant's possibilities and limitations are presented and detailed in the simulation chapter, alongside ratings from three different angles: environmental friendly, resource efficiency, and economic feasibility.

This graduation research partially shows that Circular Skin can be implemented in different circular supply chain variants, but it also raises the questions: which is the most circular variant, or the most economically feasible and for which stakeholder?

The circularity was perceived as dependent on product ownership. The variants nearest to the closed pole (the manufacturer has full ownership of the product), Vertical supply chain integration and Product as a service were understood to be environmental friendly and resource-efficient. On the other hand, user owner variants have poor circular ratings because human behaviour might influence the return process.

In economic terms, the interviewees considered the User-oriented variant easy to achieve because it is similar to the current supply chain. The buyback variants registered upper intermediate scores in the economic feasibility category due to the uncertainty regarding the return buyback value. Moreover, leasing variants registered modest ratings, with two exceptions, in the economic feasibility category because of the necessity of a significant investment.

Furhtermore, the respondents identified a relationship between product ownership and the supposed type of user. The user-oriented, the Sell and buyback or Sell and buyback without contractor variants were considered suitable for an individual client user. On the other hand, the macro-level users, like housing corporations, would benefit from the leasing variants: Product as a service and Vertical supply chain integration.

As explained in the discussion, to completely understand these meanings of the results, future research should address and analyse the implementation of the Circular Skin from two angles: environmentally and economically. I consider that my report has certain theoretical applicability, especially for Circular Skin, which is a concrete product. However, before placing the facade product on the market, many further estimative calculations should be made previously because stakeholders and investors are interested in numbers.

Based on my conclusions, the implementers could consider developing a real business model starting from the structure of my variants and comprehending the

possibilities and limitations of each circular supply chain.

To sum up, my thesis results filled the gap partially in the research regarding the possibilities and limitations of implementing the Circular Skin components into a circular supply chain. The five developed variants should be taken into account when considering how a circular supply chain works. However, the results reflect a small fraction of the total number of solutions possible for integrating the Circular Skin in the construction sector. A reader interested in how the circular economy is applied in the renovation area of the construction industry will find five variants of the circular supply chain with a set of limitations and possibilities for each variant. Further, for each variant, different circumstances were created, where theoretical knowledge is crossed with information from the interviews.
In conclusion, this graduation presents several scientific results concerning the possibilities and limitation regarding the implementation of the Circular Skin. These results could be improved with extensive research analysing other supply variants, considering other interviewees or involving a more detailed cost and environmental evaluation.

XII. Reflection

My graduation research seems to be coming to an end and I want to present the outcomes of this experience. I would like to reflect on two things: what I learn and what I created.

The first and the most meaningful results are the personal ones: what I have learned for approximately one year from this experience. To be honest, I started this thesis with almost zero experience or knowledge about Circular Economy or circular supply chains. I felt even ashamed when Anne, my supervisor, asked me how much I know about the Butterfly Model. Nevertheless, the best part is that I learned a lot. When you don't know something, the best thing is to read. And here was the first thing that I learned. I learned how to read. It is worth mentioning that Paul, my graduation chair, gave a helpful guide on reading science more effectively.

Once I had read 'enough', I began to see patterns in what we already know about my chosen topic - circular supply chains. The concepts that seem impenetrable at the beginning started to make sense for me. The theoretical background and literature review were extremely valuable for my knowledge because I learned considerably about the Circular Economy in the global context, what is a circular supply chain, Butterfly model, slowing, closing and narrowing, open/closed source/loop and the Circular Skin by TU Delft. I found it necessary to hear more about Circular Skin, and I scheduled two exploratory interviews, which were very helpful.

If I discussed what I personally learned, it is important to mention also how I contributed to scientific knowledge. My supervisors, Anne and Gerrard, told me an extraordinary thing in our initial meetings: my research results are the most important thing that I can learn as information because I am learning through it. I can, fortunately, say that I found, studied, analysed, simulated and evaluated five variants to implement a circular product, Circular Skin, in a circular supply chain.

Furthermore, I presented the stakeholders' possibilities and limitations of the implementation alongside the literature results in a clear and innovative framework that contains nine supply chain elements. Every reader who will study a variant of implementation will find the possibilities of limitation of a specific category and find an equivalence in the literature.

The graduation process has taught me how to work at the highest standards and has improved my work ethic. I understood that every day counts in developing the thesis, and I have struggled for almost one year to offer the best product to my future readers. The learnings about the circular economy, Circular Skin and circular supply chain alongside the techniques of taking an academic interview, learning the typesetting software InDesign and working through a specific methodology like 'Research through design' are just a few of the things that I have acquired through the process.

However, at the end of my thesis, I can admit that several pieces are perfectible. I consider that the methodology chosen worked very well, but I wonder if 'Research though design' is the most suitable one. Furthermore, the Charette was a fantastic day when we developed valuable variants for the implementation of the Circular Skin, but now I am thinking if five variants are enough for exploring the possibilities and limitations. Furthermore, the interviews were very beneficial for my research, but are these six interviewees the most suitable to be interviewed? First, I would like to thank each of them, Feike, Bas, Stefan, Razvan, Valentin and Maaz, for their involvement, but I consider that my thesis would be richer with more interviews from more diverse areas like an SH collecting company or an important Dutch construction contractor or a manufacturer which produce sustainable facades.

To sum up, I consider this thesis a successful, unique, challenging academic adventure where I learn how to learn, I explored new concepts and ideas, and I brought a small contribution to scientific knowledge through my research, and I also left room for further research and study.

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Appendix A

TU Delft

Interview transcript
10.09.2020

Call to order

The exploratory interview with the representants of the contractor Dura Vermeer was held online on 10.09.2020. Initially, Henk Marsman and Bram van Vliet accepted interviewer's proposal to record the interview.

Attendees

Attendees included:

- Henk Marsman – interviewee (HM)
- Bram van Vliet – interviewee (BV)
- Andrei Saceanu - interviewer (AS)

Transcript of the interview:

AS: The first official question is: I know your company is an important construction contractor and I am curious how is Dura Vermeer implicated in sustainability process?

HM: First, it's good to know that our company is divided into two separate divisions, which are infrastructure and building. And those are two different worlds. We both have our own sustainability programmes and our own goals. So, we are from the building division. We have separate companies around the Netherlands, which have their own work field and their own personnel and their own strategies. And we connect to exchange smart solutions. This building division also has one sustainability manager, which is the person who manages all the initiatives in all the different companies. He's the one setting the goals. We are in separate companies are the ones trying to fit it in projects. We have a focus on our missions; we want to lower the emissions of the buildings. We want to reduce waste. Circularity is a field of investigation for us mostly nowadays we're trying to make it part of our project, but we're searching on how to do that. And we have a more abstract mission to create a greener a greener environment. And we're a company specialised in renovation. We mainly do buildings and try to make them sustainable.

AS: I am curious to know what's your role, exactly in your company regarding the sustainability process?

HM: Bram and I are the ones in our company, who have to get the big goals, you have to translate them to our company and have to look for initiatives which fit in our projects. But to be honest, everything is in the discovery area. The Circular skin, which we are developing, is one of the examples. So there are initiatives, but we want more to have more structure with that.

AS: Now I would like to go specifically to Circular Skin. Can you describe briefly, in your own words, Circular Skin?

BV: We are not that far yet, but we plan now to make a skin using a wooden structure with insulation in it. And but we don't know what kind of insulation. We think of bio-based material, but which one we do not know. And the solution is we want to make that restriction, keeping some space between the old building and our facade. We want to fill the empty space with another kind of insulation. We designed the wooden structure to be a panel.

AS: Initially, you developed five possible design variants, which you tested afterwards. Can you tell me about that?

HM: Those variants were an outcome of the research which Anne van Stijn is doing, and she made the five variants. Each of these variants has its own unique solution for circularity. She told us about it, and that was our starting point. She presumed that the final design would be a mix out of all these principles of circularity, and that's what happened. We are making a mixed variant. Now, we search for producers and manufacturers, and their solutions to be suitable for us. But I'm going to add something to the story. That is why we are making this skin. And in the past, we made several renovations of existing housings to transform them in zero energy buildings. It was a very solid, very lean and fast method, which has the lowest possible implication for the residents who stayed in their house during this operation. And the outcome is that at the end of the operation, their house has zero energy use during the whole year, reducing the CO2 for completing our task for 2050. Every dwelling is supposed to be CO2 neutral. There are also goals to have 50% less waste in 2040, 30 and zero or none, almost none waste in 2050. So, we wanted to add this challenge call to our design solution. Our solution is made up of polished postering. Lots of elements were glued together, and this represents an environmental problem. For transforming the product into a modular one, we chose a wooden structure.

AS: Allow me to recap what we have talked about the Circular Skin design so far before we move on the next question. Do you think this design is final or it could be changed according to the partners from the supply chain (producers and suppliers)?

HM: The second option. Our company is a construction contractor. So we don't make all the components by ourselves. We put them together and find partners who make the actual elements or the components for the facade. So we're now on a quest to find the suppliers who can make components in a way that fits with our circular principles. But we're also finding many companies. Their product looks to have a circular story or circular principle, but it doesn't fit ours entirely odd. We're not ruling them out completely. For example, we said with our design team that we want to have a wooden frame for the glazing. But there are also many companies which make plastic frames, having a good story for recycling. Plastics are derived from the oil, and we don't want to have them in our facade. We can think of a future where we have a more budget horizon of our facade, which integrates the plastic frames for the windows. Same goes for the roof. The lean and light solution now is with EPS polystyrene, but it's derived from oil so we don't want it in our solution now, but we heard from the producers that they are setting up a plan to recycle EPS so they can almost endlessly recycle the material. So in the future, it's very likely that we also have EPS in the roof solution.

AS: You may find the next question difficult to answer with certainty, but I want to ask now about potential business models for the Circular Skin. How do you think is going to work? Could be a lease contract? Who will be responsible for the service and maintenance?

BV: It's hard to say anything. It depends. If you ask the client, they tell that they do not want to pay much at this moment. If you ask our partners, they don't want to invest in products at the moment, and because they don't know what the outcome would be in 20 or 25 years.

AS: My focus is mainly on the supply chain of this product, not on the technical part. The design is essential because every component should be integrated and related to a supplier or a producer at a particular moment. And now I want to ask, what's your view on the notion of circular supply chain? Do you see benefits in becoming 100% circular?

HM: We have to make big changes to our organisation if we want to be the owner of the facade and we want to be the lease accompany of the facade. There has to be a lot of changes if we're the ones responsible for the entire facade.

BV: I think that's an important question. Who's the owner of the product? Social Housing Corporation?

HM: Nowadays, Social Housing Corporations wants to be the owner of the dwelling in the facade. It's also going to be a long way and a big change for them not to be the owner of the dwelling components anymore. Maybe in the very far future, but a lot of changes have to take place in upcoming years to make that happen. We also have the financial companies who own housings. Their business model is quite different because, in the end, their only goal is to make more money than they had in the beginning. So if we can give them a solution where they don't have to put their money in a facade probably, they will be more open to it. I think we're still in the phase, where we're trying to figure out the technical solution. And our next step is to do sessions with the social housing corporations to test our ideas and to talk about the business models.

BV: I think the biggest problem is the time for the return of the investment. In 50 years or? And the problem is for companies. They consider this process unpredictable.

AS: I want to focus now on circularity. Do you think that Circular Skin will be 100% circular or not? And if you see benefits in becoming 100%, circular?

HM: The goal is to become 100% circular, but not from the first version. Our goal is to make a more circular solution than we already have.

AS: Which are the limitations for you as a stakeholder to integrate Circular Skin into a circular supply chain?

BV: Our partners represent one limitation. They sell to our clients or us a product. Will they take it back in 25 years? Are they supposed to take care of that product in time? For this moment, they cannot.

AS: I have a question now regarding the procurement of the materials. Have you already established a business relationship with specific suppliers for the materials of Circular Skin?

HM: Yes, we did. The buildings where we are focusing on are brick constructed facades. We set a goal with our design team to, at least, fix our solution for that brick facade. We integrated modularity into our solution for now. So we want to make pannels for each brick. These panels can be screwed and may be recycled or reused in another project. And we were we had some sessions with the company which makes the materials. Our next step is to make a mock-up, a little model of some of those panels to try out glue and screw solutions. For our shelves, we have the modular panels, which we can be used and reused in another project. The panel company can recycle all the materials that we're using. Another lead, one of our partners, insulates the existing dwellings. They insulate this bound, the space between the two walls. They're developing a new product which has a very high insulation value. We can use their former insulations, which are dismantled, and are good enough for our facade. We're trying to figure out if that is a

possibility to fill our facade with non-virgin insulation material. We're also discussing with a wooden framework manufacturer. The wood is a local product and has a low environmental impact. However, this wooden frame soaks up water at the long end of the beams. Well, if we fix that problem, we can use this solution.

AS: Can you explain what the space that you referred to is?

HM: We want to make the facade ready for zero energy housing. We know if you use bio-based or non-virgin materials, your whole facade would be about 30 or 40 centimetres. If you make that facade with a wooden framework, it will be very heavy and very difficult to construct. We want to have a thin technical solution which is about 20-21 cm. And we add the space behind it, which is about 15 centimetres. The wooden beams are the ones which are the weak point in your insulation. They are the accountability point. In the end, the structure will be about 35 centimetres thick.

AS: If you think I missed something and you find it necessary to mention, please add it.

BV: I'm curious how far are you in your master thesis.

AS: I can say that I almost finalised the literature review. Now I'm starting to prepare possible variants of circular supply chain. My main research question is based exactly on the possibilities and limitation of stakeholders to integrate Circular Skin into a circular supply chain.

HM: We struggle to find our suppliers and educate them in thinking about circularity. Have you found solutions for us to incorporate or what tell our suppliers?

AS: I also found out that one of the biggest problems or the main problems is called the availability of suitable partners. The literature present as a solution, the holistic approach. If everybody sees a common goal in this process of going to circularity, obviously, you can find suitable partners for you. The transition towards a circular supply chain, I think, is facilitated by the existence of a shared vision.

For the complete integration into circularity, I don't think could be made only by private operators but also with the involvement of the government. Financial incentives could change the stakeholder's behaviour, and the business market will respond to it.

HM: It's our daily struggle to find the partners, who are like you said, they have a holistic approach. Some of them are doing it; some don't. We have to educate them on doing it. I think the government forces could really stimulate it.

BV: I think we have to start with the linear business model. Initially, we should have a technical circular model with a linear business model. Afterwards, we can find out if the technical facade is working. Slowly, we can also transform the supply chain into a circular one. I think our partners have to see how can they earn money on a similar business model. First, they have to find out what's the technical solution, and then they can in.

AS: This is a lovely idea to start from a linear model and with small steps to make the transition to a circular supply chain, but to start from the beginning with a circular design.

Appendix B

TU Delft

Interview transcript
16.09.2020

Call to order

The exploratory interview with the representants of the Repurpose – second-hand material specialist was held online on 16.09.2020.

Attendees

Attendees included:

- - Bas Slager – interviewee (BS)
- - Andrei Saceanu – interviewer (AS)

Transcript of the interview:

AS: My first question is: can you describe your company briefly? What is your role within it?

BS: I advise the architect and the contractors which materials can be used and reused. I search and help to procure these materials.

AS: I know your company is working with second-hand material and I am curious how is implicated in the circularity process?

BS: It depends on the project. Every project is different. I have to search for the materials before the design of a building is finished. Otherwise, second-hand materials might not fit. For example, I search for a door, and if they have not decided yet, what kind of door it should be, I have more possibilities of second-hand items that I will present to the designer.

AS: Can you describe in our own words Circular Skin?

BS: Circular Skin will be a solution for existing buildings which do not have good insulation. So, it will be less energy-consuming. We want to make it circularly by using materials with a lower impact on the environment. These could be made in two steps. First, the materials should have a long lifespan. Moreover, secondly, it is essential to use the product for the whole designed life. You can do it in different ways with different kinds of materials. Some materials do not need much energy to be produced but do not exist for a long period. On the other hand, there are other materials like concrete which has a long lifespan by it is not used for the whole period of time.

AS: Initially you developed 5 design variants, which you tested afterwards. Can you tell me about that? Have you reached a final design?

BS: We have not reached the final design yet. These five variants were created before I joined the team. During the building process of the mock-ups, my role was to determine if the Circular Skin will work with used insulation and to find possible suppliers. That is just part of how to make things circularly. The other way around is to figure out if we can make it with materials that in the future, can be reused again.

AS: You were saying that you are responsible for procuring all the insulation that can be reused. Did you already establish contacts with other partners?

BS: Yes, I have found more than one hundred companies, mostly demolishing contractors. For the Circular Skin I hope I will search for available second hand insulation. But if I cannot find it it will be new insulation.

AS: What is your view on the notion of a circular supply chain? Do you see benefits in becoming 100% circular?

BS: We have to show our clients the future value of the circular skin. If we cannot, it will be a marketing trick for once and then it is over. That's what we have to face now. If I imagine a circular future where we reuse and recycle as much as possible, I think we can do it a lot better. However, we have to redesign our laws, our way of thinking, our way of design, we have to redesign all kinds of processes and then we are capable of making new circular buildings.

AS: Which are the limitations for you as a stakeholder to integrate Circular Skin into a circular supply chain?

BS: I have been working in this domain for eight years. I started before the word "circular" was used as a word for keeping resources in the cycle. I faced many problems. The way of how we design, build and work now is focussed around the cost. After the Second World War, we have built in a fast industrialised way. The number of people has grown, and everyone needed a place to live and to work. In all this time, the focus was on as cheap and fast as possible making the buildings. Now we are trying to make the buildings energy saving. The next step will be how we can maintain our resources, and this way of thinking is entirely new.

AS: How difficult is for you to find suitable partners in circular projects?

BS: Some companies are experimenting with products that are designed to be reused in the future. This might have a negative impact on their business because they want to sell new units. I think that our governments or the European Union should encourage the design of buildings that would permit the change of function, without any problem. Buildings could be used as office or hospitals, and that will be a significant step. If the materials that are used are entirely capable of being disassembled, the resell of these components will cover the initial costs.

AS: You may find the next question difficult to answer with certainty, but I want to ask what are the possibilities to implement Circular Skin into a circular supply chain?

BS: I can compare it with the releasing of the first iPhone; nobody was asking for an iPhone. If you would tell someone about a very expensive phone, everyone will refuse to pay more than what is normal. However, Apple was capable of making a new product with new capabilities, which is worth the price. The Circular Skin presents the same situation: a possible expensive product, which is designed for the future. For the Circular Skin, do not know the price yet, but I expect it will be more expensive. If we cannot explain or the buyer does not understand why this is a great solution, then there will be no supply chain. There will be a marketing trick working only once. It is crucial to present a solid business case where you should explain to housing corporations the value of this more expensive solution for existing housing.

AS: Have you already thought about a potential business model for the Circular Skin?

BS: Normally, the contractor should discuss with the housing corporations to see if they understand the circular benefits. The technical, cost and commercial departments should take part in these discussions. The commercial solution could be more important than the technical one because we have to sell our product.

AS: You talked previously about selling. On the other side, what is your opinion about leasing?

BS: I am thinking about two circular leasing cases: lightings from Philips and an elevator from Mitsubishi. I think for the Circular Skin, the leasing plan is difficult to be applied now. Signify Philips has a lightning system with a longer lifespan, which is more expensive. Though, over time, it could be cheaper. You pay extra for a longer lifespan, and the components within the product will be used longer. The impact of making the product over the lifespan will be lower. On the other hand, I can also lease it now from Philips. Philips could do the maintenance easily. I can buy it, or I can lease it, but leasing is more expensive than buying. Philips has to earn money right now. It will take much time before they have the initial prediction cost, which they have to pay to produce it now. In the leasing case, the client has to pay the interest. Moreover, you can take a loan for a maximum of 30 years. It is impossible to take it for 50 years. If we will make a product lasting for 50 years, what will happen with interest after this 30 years when you have to take another loan for the remaining 20 years? Might be 1% or 10%. For Mitsubishi, leasing is a good solution. Their expensive elevator with a longer lifespan and lower operational costs will always lose when a client asks for building as cheap as possible. However, leasing is more expensive than buying a Mitsubishi elevator, leasing this elevator is over time cheaper than purchasing a new one. When tendering on price, the initial price of a lease elevator is very low. That's why I think leasing is a good trick for selling these elevators with a longer lifespan. (If I would be an owner of a building for a very long time I would buy the Mitsubishi elevator instead of leasing it).

AS: I think we covered all the topics. Thank you very much for today! It was very helpful for my research!

BS: You're welcome. I wish you luck! And I give you the advice to focus on a smaller in-depth research question when you want to increase the change of doing something helping the 'circular movement' further.

Appendix C

TU Delft

Interview transcript
09.11.2020

Call to order

The interview with the representant of the Ymere - Bas Kalshoven was held online on 09.11.2020.

Attendees

Attendees included:

- - Bas Kalshoven - interviewee (BK)
- - Andrei Saceanu - interviewer (AS)

Transcript of the interview:

AS: First of all, I want to present to you my research. I developed five circular supply chains variants for the Circular Skin. These variants are: User-oriented, Sell and buyback, Sell and buy back without a contractor, Product as a service and Integrated supply chain on vertical.

The interviewer presents to the interviewee the User-oriented variant

AS: Which do you think are the possibilities and the limitations of implementing this variant?

BK: I think this is pretty close to how things work nowadays. You don't need circular facades to do this. You can always disassemble facades or any other part of a building and sell it as an owner. So, I think in terms of possibilities, I think this is easy, easy to achieve. In terms of limitations, the question is what circular about this? If the user or the product owner tries to reuse the materials, which is also possible right now, it might be very circular. However, I think the limitations of this model are large because of the behaviour of people. The problem is generated by how the user is managing the materials after disassembling.

AS: Now, I would like you to offer ratings for this variant. We have three categories. The first category is environmentally friendly. How environmentally friendly this thing is this category and why?

BK: Well, it depends on the user's behaviour. Unfortunately, this variant does not support precisely proper environmental friendly behaviour. I will rate this variant with two stars for both environmental friendly and resource efficiency. For the economic efficiency category, I give five stars because it is close to what has already been done. That's why it is easier to implement it.

AS: Perfect. Thank you. Let's move to the second variant.

The interviewer presents to the interviewee the Sell and buyback variant

AS: Which are the possibilities and limitations to implement it?

BK: Well, I think this variant is reasonably easy to achieve because it is possible to explain it to the user. In terms of limitations, the long lifespan of the product is problematical for the estimating and guaranteeing the buyback. The average company has a lifespan of about 40 years or something. The lifespan of a facade could be longer than the lifespan of the manufacturer and it might affect the reintegration of the product in the loops.

AS: Thank you. We can move forward to the rating part.

BK: I will award three stars for environmetal and resource categories. The circularity might be achieved for all the different variants. For this variant, it is important how the manufacturer manage the buyback product. It could be very environmentally friendly if there is no waste. Unfortunately, nobody can guarantee that. Companies which want to incentivise this, largely, are environmentally driven. Although the model does not typically support it. For the economic feasibility, I will award four stars, one less than the previous one.

AS: Thank you. The next variant is selling buyback without the contractor.

The interviewer presents to the interviewee the Sell and buyback without contractor variant

AS: Which are the limitations and possibilities of this variant different from the previous one?

BK: The efficiency of assembling and disassembling of the facade could represent an incentive, also, for the manufacturer to make it easier. The limitations are similar to the previous model.

AS: How would you rate this variant?

BK: I consider that this variant has the same environmental impact. 3 stars. The resources could be better managed. By using more efficient components for the assembling, it might require fewer resources. 3.5 stars for resource efficiency. And 4 stars for the economic feasibility category because by letting the manufacturer install the facade.

AS: Perfect. Thank you very much. Let's move on to the first variant, where the user is not the owner of the Product. This variant is called "Product as a service".

The interviewer presents to the interviewee the Product as a service variant.

AS: Which do you think are the possibilities and the limitations of implementing this variant?

BK: I think the possibilities are enormous, but also the way to get there is very difficult. Our core business is represented by offering houses to people with low income. In this variant, my company will not need to maintain or build the facades. With this variant, we can go to our core business and ask the manufacturer to lease us the facade. It would drastically change the landscape of our business. The limitations here are related to financial investment because it requires a lot of money from the manufacturer.

AS: How would you rate this variant?

BK: Regarding to environment category, I will rate similar this variant as the previous one, 3 stars. In every business model, money has to be made. This variant does not explicitly support environmentally friendly products or something like that. Because also, well, money has to be made with this product. The resource efficiency of materials should be good because of the necessity of generating profit from the leasing. The leasing encourages the efficient management of resources. I will award 5 stars. Now, the economic part is the

difficult one, because it requires deep pockets. It requires a shift in thinking for the owners of facades now and because it is a decision you make for such a long lifespan with the lease. I think this is going to be a problem for the decision-makers. Are they willing and make decisions, which make you have a lease contract for? I will give 2 stars.

AS: Perfect, thank you. And now we're going to move to the last one, and which is also the most extreme one. It's an integrated supply chain on vertical.

The interviewer presents to the interviewee the Integrated supply chain on vertical variant.

AS: Which are the limitations and possibilities of this variant?

BK: This case is ideal for the user. You can start a housing company right away with not a lot of money because this huge company will provide different components. I think this variant would help many users. Maybe a little bit the same as a previous model. However, again, you can see there is a massive possibility for users, but getting it done by the manufacturer. The manufacturer needs much money to invest. That is the limitation of this model, I think. It requires a mind shift of the users. If you make this user friendly as you can, I think there's a market for it.

AS: Okay, I purpose to move to ratings now.

BK: Taking about the same leasing system, I will rate similar to the previous one. 3 stars for environmentally friendly and 5 stars for resource efficiency. I consider the economic feasibility is improved in this variant, because all the processes are in one hand. And if you started, you have it.

AS: Thank you very much for today. It was a great help. And I will send you the transcript to give your accept for it. Thank you.

BK: Thank you. Good bye!

Appendix D

TU Delft

Interview transcript
04.11.2020

Call to order

The interview with the representant of the Villa Nova- **Feike Laane was held online on** 04.11.2020**.**

Attendees

Attendees included:

- - Feike Laane - interviewee (FL)
- - Andrei Saceanu – interviewer (AS)

Transcript of the interview:

AS: I want to thank you for taking part in my graduation research. I developed five circular supply chains variants for the Circular Skin. These variants are: User-oriented, Sell and buyback, Sell and buy back without a contractor, Product as a service and Integrated supply chain on vertical.

The interviewer presents to the interviewee the User-oriented variant

AS: Which do you think are the possibilities and the limitations of implementing of User-oriented variant?

FL: I think this variant is the least circular variant because it does not incentivise the user to disassemble and resell the components. The circularity is conditioned by the user. Still, this is the easiest way to implement for the Circular Skin. Usually, it is cheaper to just demolish and get rid of the materials. This is the main limitation. Also, the client has to pay for the material passport.

AS: Thank you very much. Now, I would like you to rate this variant. There are three types of ratings: environmentally favourability, resource efficiency and economic feasibility. How environmentally friendly this thing is this category and why?

FL: I think this variant presents a risk that after demolishing the materials to be thrown away. There is no incentive for reuse. So, I will give 2.5 stars.

Also, 4 stars for resource efficiency, I guess. Because, as well, there is no incentive to have little resources except for making it cheap. So when you use little resources, it's also cheap for a manufacturer, and then it's more likely that the client will buy it. I am thinking that the manufacturer has an incentive to make it resource efficient when he gets the materials back. Also, the manufacturer is not very interested in using thick over-dimensioned elements because the user has ownership of the product. Moreover, I consider this variant very applicable for the current economy. 5 stars.

AS: Perfect. Thank you. Let's move to the second variant.

The interviewer presents to the interviewee the Sell and buyback variant

AS: Which are the possibilities and limitations to implement it?

FL: This variant is close to the previous one, except that the manufacturer will give the user an incentive for returning the disassembled components. It is helpful that the manufacturer starts analysing the disassembling and returning processes. Maybe new techniques will be developed. There is, actually, this is not really the user's risk. It is not the only reason, because you can always sell it back to someone else. Unfortunately, these techniques could be restricted only for the manufacturer, closed source. There is, of course, the limitation is represented by the necessity of trust or faith in the economy. The existence of manufacturers after 30 years is questionable because the facade lifespan is very long and the manufacturer could go bankrupt.

AS: Thank you. We can move forward to the rating part.

FL: In the environment category, this variant is better than the previous one because of the buyback incentive. So let's say 3 stars. I don't really think this variant is resource-efficient. The manufacturer wants to receive the components in good form after the buyback. Probably, the manufacturer will use over-dimensioned parts or better materials. 3 stars. The economic economically is diminished because the client has to pay in advance for the buyback. The client is buying extra-services. Let's say 4.5 stars.

AS: Thank you. The next variant is selling buyback without the contractor.

The interviewer presents to the interviewee the Sell and buyback without contractor variant

FL: I understand that the manufacturer will apply the facade to the existing building. The manufacturer is also the contractor.

AS: Exactly. Which are the limitations and possibilities of this variant different from the previous one?

FL: I suppose that the contractor will improve the installation of the facade and the whole construction process. A limitation could be represented by maintenance/reparation process. If something is going wrong, parties might start pointing to each other. In the current economic model, subcontractors point a lot to each other. The user might be tempted to shop for the lowest price between different companies, neglecting the quality of the services.

AS: How would you rate this variant?

FL: It becomes a little bit more environmentally friendly, I think. So let's give it three, three and a half stars because the manufacturer might preserve better the components by a proper installation. 3 stars for resource efficiency, no variations from the last variant. I think it will be a little bit better economically if the same company assembles and disassembles the facade. 4.5 stars.

AS: Perfect. Thank you very much. Let's move on to the first variant, where the user is not the owner of the Product. This variant is called "Product as a service".

The interviewer presents to the interviewee the Product as a service variant.

AS: Which do you think are the possibilities and the limitations of implementing this variant?

FL: In this variant, there is a significant dependence of the product owner, the manufacturer. I like that this variant prioritises the environment over the money. It seems quite risky, depending on the future history of the manufacturer. The business plan of the housing corporation could be affected by a bankrupt of the manufacturer. It's an advantage for the user because it can use the product without a big investment. Companies have strict budgets and, in this variant, the prediction of costs over time is facile.

AS: How would you rate this variant?

FL: The environmental benefits of the variant are granted. So, 4 stars. The resource efficiency is improved by using better materials to last a long period of time, reducing, in the end, the material consumption. The manufacturer, who is the is motivated to minimise the waste of components. I think you put a little extra material initially in to have it resilient, but it will be recovered after the lifespan. Let's say, for 4.5 stars. For housing corporations, this variant is very economically feasible. I think for the private client, for instance, this variant is hard to be used but not impossible. 3 stars

AS: Perfect, thank you. And now we're going to move to the last one, and which is also the most extreme one. It's an integrated supply chain on vertical.

The interviewer presents to the interviewee the Integrated supply chain on vertical variant.

AS: Which are the limitations and possibilities of this variant?

FL: I see that this variant is dedicated to the big contractors, which are becoming enormous. In the Netherlands, there are many contractors, which are trying to become larger and to expand abroad. One limitation might be the problematic management of these giant corporations. Many contractors also reduce their activity after a while abroad. They're trying to focus again on the Dutch market because it was not really a success to become that large. Usually, these gigantic corporations are focussed on consumer products, final goods like Apple and Microsoft, not leasing performances. However, the advantages are clear management practices: you cannot point to each other if something is going wrong. In the construction industry there several holding companies, which are composed of different contractors. They can compete for the same project or form an alliance when it is required.

AS: Okay, I propose to move to ratings now.

FL: Having a similar leasing system as the previous Product as a service variant, I will award the 4 stars for envinromentally friendly category. Also, it is improbable to lose resources in the process. 5 stars for resource eficiency. When you become such a giant company, the chance to fail is smaller. Even if they have a delicate financial situation, the governments will help them with loans, to not bankrupt. On the other side, it is difficult to become that large. So 3.5 stars for economical feasibility.

AS: Thank you very much for today. It was a great help. And I will send you the transcript to give your accept for it. Thank you.

FL: Thank you. Good bye!

Appendix E

TU Delft

Interview transcript
11.11.2020

Call to order

The interview with the representant of the *Vitalis*- *Razvan Bobeica* was held online on 11.11.2020.

Attendees

Attendees included:

- - Razvan Bobeica - interviewee (RB)
- - Andrei Saceanu – interviewer (AS)

Transcript of the interview:

AS: I am very grateful for having you as an interviewee in my graduation research. I developed five circular supply chains variants for the Circular Skin. These variants are: User-oriented, Sell and buyback, Sell and buy back without a contractor, Product as a service and Vertical supply chain integration.

The interviewer presents to the interviewee the User-oriented variant

AS: Which do you think are the possibilities and the limitations of implementing of User-oriented variant?

RB: I think this variant might be the most disadvantageous for the user in terms of costs because the user has to pay for the product price and different services like installation, dismantling and maintenance. One possibility to incentivise the user to sell the components to an SH collector is governmental support, maybe why European funds. On the other hand, the user has the freedom to sell, resell or use the components at his/her convenience. Unfortunately, this aspect could affect the circular process of returning the components.

AS: Thank you very much. Now, I would like you to rate this variant. There are three types of ratings: environmentally favourability, resource efficiency and economic feasibility. How environmentally friendly this thing is this category and why?

RB: The return process is strictly related to the user's behaviour. This fact might determine the loss of materials and the necessity of producing new components with primary raw material. I will award 3 stars for first two categories and 5 stars for the economic feasibility because the variant is easy to implement.

AS: Perfect. Thank you. Let's move to the second variant.

The interviewer presents to the interviewee the Sell and buyback variant

AS: Which are the possibilities and limitations to implement it?

RB: Here, I found it quite challenging to determine the facade's future value after 30 years. However, there might be mistrust of the user in the future of the manufacturer. The buyback will not be possible in case of the manufacturer's bankruptcy. I consider that the manufacturer could offer a discount for purchasing a new facade to incentivise the user.

AS: Thank you. We can move forward to the rating part.

RB: I think that environment is well protected in this variant because of the incetive for the user to return the components, limiting the waste. 4 stars for environmental friendly. The resource efficiency is affected by multitude of contractors involved in the construction process, so 3 stars. I consider this variant less fessible because I am not sure that the buyback will be efficient. 3 stars

AS: Thank you. The next variant is selling buyback without the contractor.

The interviewer presents to the interviewee the Sell and buyback without contractor variant

AS: Which are the limitations and possibilities of this variant different from the previous one?

RB: This variant presents advantages for both user and manufacturer. The user's risk is lowered because the manufacturer will be responsible for the assembling of the facade. Furthermore, the manufacturer has the possibility to install the Circular Skin skillfully without damaging the product. However, the installation of the facade is an additional service, which will increase the price of the Circular Skin. A deposit could represent a possibility but also a limitation because the problem of refund is still uncertain.

AS: How would you rate this variant?

RB: The integration of the installation process in the manufacturer's services is helpful for resource efficiency and economic feasibility. The facade is operated in the critical phases of the construction by only one party, maintaining components undamaged. 4 stars for environmental friendly and 5 stars for resource efficiency. The Circular Skin's economic implementation is straightforward because the user will have all services included in the facade's price: 4 stars.

AS: Perfect. Thank you very much. Let's move on to the first variant, where the user is not the owner of the Product. This variant is called "Product as a service".

The interviewer presents to the interviewee the Product as a service variant.

AS: Which do you think are the possibilities and the limitations of implementing this variant?

RB: I see this variant as a remarkable opportunity for the user to start a project without investing considerably. Furthermore, the manufacturer has the possibility to register higher revenues for the long term. The main limitation of this variant is the financial constraint of the large investment for the manufacturer. Without significant investment, the manufacturer cannot start this business. For the user, the future fluctuation of the leasing fees might be problematic.

AS: How would you rate this variant?

RB: In this variant, the return process is secured because the manufacturer will recover the product back. The variant is very advantageous in terms of environment because the same facade is re-used until end of component's lifespan: 5 stars. The resource efficiency is almost flawless, but I have doubts about the remanufacturing process: 4 stars. However, economical implementation is challenging because of the necessity of a significant initial investment: 3 stars.

AS: Perfect, thank you. And now we're going to move to the last one, and which is also the most extreme one. It's an integrated supply chain on vertical.

The interviewer presents to the interviewee the Vertical supply chain integration *variant.*

AS: Which are the limitations and possibilities of this variant?

RB: I think this variant is applicable only for existing giant corporations. Only these companies can afford to invest enormously in developing their company on vertical for having suppliers, contractors, and manufacturers' centres integrated. This investment should be recovered from the lease fees, conducting to higher costs for the user. On the other hand, this is the only variant that can ensure the Circular Skin's full circularity. Further, the company should promote its circular and sustainable design for marketing purposes, generating user's awarness.

AS: Okay, I propose to move to ratings now.

RB: This variant is definitely the most performant one in the first two categories because all processes (procurement, manufacturing and construction) are integrated, and the loss of material is almost zero. 5 stars for environmentally friendly and resource efficiency. However, the applicability of this variant is reduced, because only large corporations can adopt and adapt to it: 3 stars for economic feasibility.

AS: Thank you very much for today. It was a great help. And I will send you the transcript to give your accept for it. Thank you.

RB: Thank you. Good bye!

Appendix F

TU Delft

Interview transcript
16.11.2020

Call to order

The interview with the representant of the ***TERRA CONSTRUCT*** – *Stefan Cantu* was held online on 16.11.2020.

Attendees

Attendees included:

- - Stefan Cantu - interviewee (SC)
- - Andrei Saceanu – interviewer (AS)

Transcript of the interview:

AS: Thank you for accepting this interview for my graduation research. I developed five circular supply chains variants for the Circular Skin. These variants are: User-oriented, Sell and buyback, Sell and buy back without a contractor, Product as a service and Vertical supply chain integration.

The interviewer presents to the interviewee the User-oriented variant

AS: Which do you think are the possibilities and the limitations of implementing of User-oriented variant?

SC: I consider that this variant is suitable for the individual clients who want to assemble it by themselves. On the other hand, I don't think it is applicable for a bigger scale, like a residential developer. The fact that different unspecialiazed contractors will operate the facade in different phases could damage the components. Also, this variant does not encourage the stakeholders to be sustainable. However, the material passport and eco-labelling are great instruments to determine the user to return the products.

AS: Thank you very much. Now, I would like you to rate this variant. There are three types of ratings: environmentally favourability, resource efficiency and economic feasibility. How environmentally friendly this thing is this category and why?

SC: This variant has nothing sustainable except the design, and I will award three stars in the environmental category. The resource efficiency is affected by the damages, produced by different contractors who are operating the facade, and the uncertainty regarding the return of components. 1 star for resource efficiency. The economical implementation is similar to the vast majority of the construction products- 5 stars.

AS: Perfect. Thank you. Let's move to the second variant.

The interviewer presents to the interviewee the Sell and buyback variant

AS: Which are the possibilities and limitations to implement it?

SC: May I see the components of the facade again? Ok, I consider that these components, the insulation, the timber frame and the wood panel, will not be very valuable after several years. I think this buyback could also be a possibility and a limitation at the same time. The buyback idea will incentivise the user to return, but the components' future value will be reduced. Compared to the previous variant, Sell and Buyback supports the circularity and reduce the waste of materials.

AS: Thank you. We can move forward to the rating part.

SC: This variant has an improved, but still not perfect, mechanism of returning and collecting the components. So, I will award 4 stars for environmental friendly and 3 stars for resource efficiency. The economic feasibility is decreased because of the uncertainty regarding the payment of buyback, 4 stars.

AS: Thank you. The next variant is selling buyback without the contractor.

The interviewer presents to the interviewee the Sell and buyback without contractor variant

AS: Which are the limitations and possibilities of this variant different from the previous one?

SC: I noticed that the only difference between this variant and the previous one is that the manufacturer is performing the installation of the facade. Here, I appreciate the constructive process's linearity because only one stakeholder is involved in building, assembling and disassembling the Circular Skin. This change will not increase the manufacturer's expenses considerably because the construction and transportation departments also exist in the previous variant. The open-source aspect of supply chain represents the limitation. I consider that also the manufacturer should maintain the facade.

AS: How would you rate this variant?

SC: I think if the manufacturer performs the installation, the teams will take more time to complete the task than a regular company because of the lack of market pressure. Another contractor will want to try to execute fast and precise. The time delays in the construction site are definitely not environmentally friendly: 3 stars. On the other side, there is an improvement in the resource efficiency category: 4 stars. Economic feasibility: 4 stars.

AS: Perfect. Thank you very much. Let's move on to the first variant, where the user is not the owner of the Product. This variant is called "Product as a service".

The interviewer presents to the interviewee the Product as a service variant.

AS: Which do you think are the possibilities and the limitations of implementing this variant?

SC: I understand that the user can ask later to replace the facade with another one. I think this is helpful for the user because the facade could be updated with the latest technologies. The technical solution for a modular facade like this might be more expensive than a fixed facade, for example, the first variant when the manufacturer did not have the certainty of recovering the facade. Furthermore, if we are talking about a neighbourhood of residential housing, the aesthetical changes could be used as a design improvement and a marketing strategy. However, I consider this variant not indicated for an individual client for a long-term contract because the costs are definitely higher.

AS: How would you rate this variant?

SC: This variant is environmentally adjusted for avoiding the loss of materials by returning precisely the components back to the product owner (manufacturer). 5 stars for the first two categories. I consider

implementing this variant challenging because of the requirement of a substantial investment from the manufacturer. If the investment condition is achieved, the rest of the process is still without too many risks. 3 stars

AS: Perfect, thank you. And now we're going to move to the last one, and which is also the most extreme one. It's an integrated supply chain on vertical.

The interviewer presents to the interviewee the Vertical supply chain integration *variant.*

AS: Which are the limitations and possibilities of this variant?

SC: If a corporation decides to develop such a facade, I think it is possible. The real limitation is to sustain all these departments of the company financially for a long time. I predict high costs for the manufacturer here. However, the user is exempt from any risks in this variant. The most important advantage is that the manufacturer will recover all the facades' components and reuse them.

AS: Okay, I propose to move to ratings now.

SC: Personally, I like this model. I consider that this is the only possibility to implement the leasing of the facade. Again, I will give 5 stars for the environment and resource efficiency because the manufacturer's interest is to recover the components. Moreover, a giant corporation is the only possible investor in this project. 5 stars for economic feasibility.

AS: Thank you very much for today. It was a great help. And I will send you the transcript to give your accept for it. Thank you.

SC: Thank you. Good bye!

Appendix G

TU Delft

Interview transcript
17.12.2020

Call to order

The interview with *Maaz Khan*, *in the role of the manufacturer*, was held online on 17.12.2020.

Attendees

Attendees included:

- - Maaz Khan - interviewee (MK)
- - Andrei Saceanu – interviewer (AS)

Transcript of the interview:

AS: I am very grateful for having you as an interviewee in my graduation research. I developed five circular supply chains variants for the Circular Skin. These variants are: User-oriented, Sell and buyback, Sell and buy back without a contractor, Product as a service and Vertical supply chain integration.

The interviewer presents to the interviewee the User-oriented variant

AS: Which do you think are the possibilities and the limitations of implementing of User-oriented variant?

MK: As a manufacturer, I consider this variant to implement the facade is somehow simple because it follows the IKEA model. The manufacturer has only to prepare a business model focused on selling the product. After years, the manufacturer should take into consideration another source of materials: the ones that are coming from the users. Here, these multiple processes represent the possibility of developing local jobs in collecting, second-hand, and remanufacturing.The real limitation is the return of the materials back from the users. Nobody will want pay for transport and return. Moreover, the manufacturer should consider that many components might be damaged or unusable for the remanufacturing process.

AS: Thank you very much. Now, I would like you to rate this variant. There are three types of ratings: environmentally favourability, resource efficiency and economic feasibility. How environmentally friendly this thing is this category and why?

MK: The environment category and resource efficiency are mutually dependent on one another. This variant does not present a perspective of recovering the facade's components. I will give 2 stars for both categories. The economic implementation is unquestionable because the variant is concentrated on product sellings; I will award 5 stars.

AS: Perfect. Thank you. Let's move to the second variant.

The interviewer presents to the interviewee the Sell and buyback variant

AS: Which are the possibilities and limitations to implement it?

MK: I consider that this variant is definitely more circular than the previous one. The return process of the components represents the limitation. The user is responsible for contracting a demolition company to dismantle the facade. The transport back to the manufacturer is questionable because it might increase the price of the facade. The transportation costs could increase because the components should be collected and *transported* from the user location to the manufacturing centre. This process could be irritating and might determine the user to throw the components away. Unfortunately, the manufacturer will also face multiple difficulties like sorting and repairing (the components might be damaged from negligently disassembling). On the other hand, this variant offers a reason for the connection between stakeholders, the buyback.

AS: Thank you. We can move forward to the rating part.

MK: I see a discrepancy between the manufacturer and the user in the initial and return phases. I will award 3 stars for environmental friendly and resource efficiency because the user would return the components in the ideal situation, but there is no guarantee. In the economic feasibility category, I will award 2 stars.

AS: Thank you. The next variant is selling buyback without the contractor.

The interviewer presents to the interviewee the Sell and buyback without contractor variant

AS: Which are the limitations and possibilities of this variant different from the previous one?

MK: In this variant, the role of the manufacturer is more significant. The installation performed by the manufacturer can limit the damages of the product because qualified workers do the work. The limit of the damages preserve the components and facilitate their reuse after the return. However, this variant presents higher costs of the facade and increases the risk for the manufacturer. A significant risk for the manufacturer is the foresight of expenses due to the buyback payments, affecting directing manufacturer's income.

AS: How would you rate this variant?

MK: I believed this variant is resource-efficient because one stakeholder operates all the assembling/disassembling process: 4 stars. The environmental impact is similar, but the economic feasibility is improved to 4 stars because of reducing the involved stakeholders' number.

AS: Perfect. Thank you very much. Let's move on to the first variant, where the user is not the owner of the Product. This variant is called "Product as a service".

The interviewer presents to the interviewee the Product as a service variant.

AS: Which do you think are the possibilities and the limitations of implementing this variant?

MK: I consider this variant designed to attract new clients. I think it could be attractive for housing corporations because of the lack of spending much money in the early phases. Another possibility of this variant is the manufacturer's motivation to design a facade that is efficient and easy to assemble, disassemble and maintain. The waste of this variant is minimal, and the circularity is unquestionably achieved. However, the flow of used

components is hard to be predicted because the user can terminate the contract earlier than the initial prediction or ask for extensions.

AS: How would you rate this variant?

MK: By holding the ownership of the product, the manufacturer ensures the circularity of the components. Being a closed source and a closed-loop, the manufacturer will optimize the design to make the product resource-efficient. The only vulnerable spot of the circularity process is located in the procurement phase of materials from suppliers. There are 4 stars for environmental friendly and resource efficiency. However, the economic feasibility is difficult because the construction sector is not used with the leasing process. Furthermore, the companies will not be very enthusiastic about investing in the development of a product, which will return the investment after a long time. 3 stars for economic feasibility.

AS: Perfect, thank you. And now we're going to move to the last one, and which is also the most extreme one. It's an integrated supply chain on vertical.

The interviewer presents to the interviewee the Vertical supply chain integration *variant.*

AS: Which are the limitations and possibilities of this variant?

MK: Wow! This one is fascinating. The possibilities are huge here because of the resources of this company. I think the manufacturer company can promote innovation or develop a very circular design. The integration of different branches in the same company would dynamise the processes and reduce the waiting time with procurement. For example, I believe that the transport distances could be reduced from supplier to manufacturing point and further to the end-use location, decreasing the carbon footprint. I also believe that regulation could be modified for these particular companies to support them: for instance, tax reduction for limiting the carbon footprint. The limitation is the requirement for a large corporation to invest in this project. Just a few companies in the Netherlands have the financial power to implement such a project.

AS: Okay, I propose to move to ratings now.

MK: I will award 5 stars for environmental friendly and resource efficiency categories because now there is only one company which operates the facade's components in all phases. However, compared to the previous variant, the current one is even more restricted because the initial investment is more significant. 3 stars for economic feasibility.

AS: Thank you very much for today. It was a great help. And I will send you the transcript to give your accept for it. Thank you.

MK: Thank you. Good bye!

Appendix H

TU Delft

Interview transcript
19.11.2020

Call to order

The interview with the representant of the *MasterBuild*- *Valentin Raducanu* was held online on 19.11.2020.

Attendees

Attendees included:

- - Valentin Raducanu- interviewee (VR)
- - Andrei Saceanu – interviewer (AS)

Transcript of the interview:

AS: I want to thank you for taking part in my graduation research. I developed five circular supply chains variants for the Circular Skin. These variants are: User-oriented, Sell and buyback, Sell and buy back without a contractor, Product as a service and Integrated supply chain on vertical.

The interviewer presents to the interviewee the User-oriented variant

AS: Which do you think are the possibilities and the limitations of implementing of User-oriented variant?

VR: I think the uncertainty at the end of the product lifespan could be problematical because the user cannot anticipate the possibilities of selling the facade components. Furthermore, an important question is who might be the buyers of the components. In this supply chain, there are high chances for the components to waste. However, this variant presents limited risks for the manufacturer because it uses the current linear economic model where the market risks are partially known.

AS: Thank you very much. Now, I would like you to rate this variant. There are three types of ratings: environmentally favourability, resource efficiency and economic feasibility. How environmentally friendly this thing is this category and why?

VR: I will give 1 star for both environmental friendly and resource efficiency categories because of the possible loss of materials. The economical implementation of the variant is simple because it is similar to the current construction supply chain. 5 stars.

AS: Perfect. Thank you. Let's move to the second variant.

The interviewer presents to the interviewee the Sell and buyback variant

AS: Which are the possibilities and limitations to implement it?

VR: The buyback programme could represent a limitation. In case the existing building is reaching the end of the lifespan, the users will not want another facade. Here the manufacturer has the possibility to offer also a direct financial incentivise. The manufacturer will also have increased operational costs with the collecting and sorting centre for all the components. Moreover, the manufacturer might encounter difficulties in predicting and planning the flow of materials coming from buyback return. The significant possibility for the manufacturer is the procurement of secondary materials at cheap charges. Also, the European Union encourages economic entities to develop their activities to become circular and sustainable. The only practical way to achieve this ambitious goal is to incentivise businesses using European funds or tax reduction.

AS: Thank you. We can move forward to the rating part.

VR: This variant improves the environment and resource efficiency part, but it lowers the economic feasibility because of the buyback. Please don't understand me wrong, the buyback could work, but it was not used in the construction industry. 3 stars for all three categories.

AS: Thank you. The next variant is selling buyback without the contractor.

The interviewer presents to the interviewee the Sell and buyback without contractor variant

AS: Which are the limitations and possibilities of this variant different from the previous one?

VR: The manufacturer's involvement in the installation process could be proper for the supply chain for decompressing the procedures for the user. However, this action will transfer the risk from the user to the manufacturer. This transfer of activities significantly enlarges the demanded dimension of the manufacturer company.

AS: How would you rate this variant?

VR: The variant without a separate contractor, I don't think is improving the environmental friendly and resource efficiency categories: 3 stars for both. Moreover, the manufacturer's necessity for creating specialised teams to install the facade negatively influences economic feasibility. 2 stars

AS: Perfect. Thank you very much. Let's move on to the first variant, where the user is not the owner of the Product. This variant is called "Product as a service".

The interviewer presents to the interviewee the Product as a service variant.

AS: Which do you think are the possibilities and the limitations of implementing this variant?

VR: The Product as a Service variant represents a solution for the macro-level users, like the housing corporations or residential developers. For them, the leasing options would replace the necessity of investing a lot of money. Nonetheless, not having the product's ownership might determine the user to have abusive behaviour: negligence, vandalism or avoidable accidents.

AS: How would you rate this variant?

VR: I consider that all the rating categories are related to the future of the manufacturer in this variant. Not all companies can offer to lease facades to clients. This variant is an exclusive variant for companies with high financial possibilities. However, if the economic feasibility is achieved, also the first categories are successful. Still, if the manufacturer will go bankrupt after a few years, the circularity is not fulfilled anymore. I will award 3 stars for all the categories.

AS: Perfect, thank you. And now we're going to move to the last one. It's an integrated supply chain on vertical.

The interviewer presents to the interviewee the Vertical supply chain integration *variant.*

AS: Which are the limitations and possibilities of this variant?

VR: The most evident possibility for the manufacturer and the planet is that every material is recovered. The improvement of the material flow will lower the production cost and create secondary material source. The limitation of this variant is the small niche of giant companies which can design and produce the facade. Furthermore, I am not convinced that this variant would attract individual users because they will have to pay for services and not for the product itself.

AS: Okay, I propose to move to ratings now.

VR: This variant is similar to the previous one from the point of view of the first two categories. The manufacturer, the product owner, is directly interested in recovering the components. 5 stars for environmentally friendly and resource efficiency. I think you can identify the possible companies able to produce the facade because they are just a few. If a big company accepts to produce the facade, they will have the capacity to manage this project. Furthermore, the chances of a possible bankruptcy are limited. 5 stars

AS: Thank you very much for today. It was a great help. And I will send you the transcript to give your accept for it. Thank you.

VR: Thank you. Good bye!