LUND UNIVERSITY
School of Economics and Management

Bachelor in Economy and Society

The Development of Circular Economy Within the Building Industry

A study focusing on Sweden and Denmark

by
Lucile Corcoran
lu5324co-s@student.lu.se

The building industry is one of the most polluting sectors and consumers of resources. Simultaneously, demand for housing is increasing and resources are becoming scarce. Therefore, circular practices have gained emphasis to possibly leverage this problem. This paper aims to try and explain how the development of circular practices can be explained by the Innovation Diffusion Theory (IDT). This paper adopts a qualitative method with semi-structured interviews to gain a deeper understanding of the subsequent issues. Here, as circular practices are at their early stage of development, the IDT framework was used to explain what is hindering and enabling the development of these practices in the early stage. It also sheds some light on possible ways to further develop circular practices for this innovation to perhaps be more diffused. Therefore, the results highlighted the result that the lack of regulations and financial incentives is slowing down the innovation adoption process since no framework is placed, which feeds risk perception. The results also showed that the development of technologies and collaborative networks has a positive impact on the rate of diffusion of circular practices but still remains slow as of today. Therefore more collaboration between the private and the public sector is needed to make the building industry more sustainable.

Course code: EOSK12
Bachelor's Thesis (15 credits ECTS)
May 2024
Supervisor: Kirk Scott
Examiner: Prince Young Aboagye
Word Count: 12358
Key words: Circular Economy, Circular Building, Waste Reduction, Ressource Management

Acknowledgements

I would like to express my thanks to my supervisor, Kirk Scott, for his guidance throughout this thesis as well as to all the interviewees who took the time to discuss circular building practices with me. I also want to express my gratitude to my family and friends for their support.

Table of Contents

List of Figures

* *All adapted figures were illustrated by the author*.

List of abbreviations

CE: Circular Economy

BIM: Building Information Modeling

IDT: Innovation Diffusion Theory

1 Introduction

“The greenest building is the one that already exists” are the words of former American Institute of Architects president, Carl Elefante (Adam, 2019, n.p.). Indeed, the construction industry is the leading consumer of natural resources globally, consuming 40% of the resources, creating 40% of the global waste and is responsible for a third of the total CO2 emissions (Eberhardt et al. 2022; Owojori & Okoro, 2022; Pomponi & Moncaster, 2017). Simultaneously, the global population living in urban areas is estimated to increase to 70% by 2050 (United Nations, 2024). This leads to more pressure on the need to extract resources to construct buildings as housing demand is increasing, as well as other challenges such as energy and transportation (Owojori & Okoro, 2022; United Nations, 2024).

As resources are finite but demand is growing, there is a constraint that needs to be solved through new solutions. In response to this pressing challenge, several studies have investigated the concept of circular economy practices, which has gained traction recently, as a potential solution to reduce pollution, energy consumption, resource depletion and minimizing waste in the construction industry (Eberhardt et al. 2022; Pomponi & Moncaster, 2017). Indeed, the development of the Agenda 2030 by the United Nations and the creation of the Sustainable Development Goals (SDG) has emphasised the importance of making the building industry more sustainable and resilient (Owojori & Okoro, 2022). In this context, Circular Economy aligns with SDG 11, which aims to make cities more sustainable and SDG 17, which emphasizes the importance of promoting collaboration between actors such as the private and public sectors (Owojori & Okoro, 2022).

Therefore, in the building industry, the major objective of circular economy is to eliminate waste by adopting strategies such as recycling, reducing and reusing, to further extend the lifetime of resources (Górecki et al. 2019; Hamida et al. 2023; Hjaltadóttir & Hild, 2021). However, they argue that despite the recognized benefits of circular economy practices, their widespread adoption faces numerous barriers and challenges

1.1 Aim and Scope

This paper aims to investigate the innovation diffusion of circular practices within the building industry, shedding light on how these practices are adopted and spread among stakeholders via the Innovation Diffusion Theory (IDT) by Roger (1983). By using IDT, this study aims to analyze the patterns of innovation adoption and explore the barriers hindering the development of circular practices, as well as potential solutions. This research has the potential to advance knowledge on circularity in the building sector and develop solutions for its development, with a particular emphasis on the pivotal role of the private sector via new technologies and digitalization in mitigating risk perception. Therefore, through the lens of IDT, the study aims to address how risk perception affects the rate of circular practice adoption among different stakeholders. Furthermore, instead of focusing on the whole construction industry, this study will focus only on the building sector. Moreover, this study is of interest to many stakeholders working in the building industry, since it is crucial for all actors to be involved in this transition to potentially implement these practices on a larger scale. Hence, it also provides them with insights about new potential enablers of circular economy (CE).

To delimitate the study, the paper will focus on Sweden and Denmark as these countries are among the few pioneers in the field. Due to the novelty of this research field, the study will focus on the development of CE from the beginning of the 21st century and mostly on the last ten years.

1.2 Contribution

As previous research have done so, the focus and originality of this paper will be to look at the diffusion of circular practices in the building industry through the lens of Rogers' IDT Theory to see how it applies and can fit some assumptions along the way. As circular practices are in the early stage of development and adoption, the thesis will mostly focus on the perceived characteristics that influence the rate of adoption to try and explain its early diffusion in early settings, and how it could be scaled and more widely diffused.

1.3 Research Question

How can the diffusion and adoption of circular practices in the building industry be explained by the innovation diffusion theory?

1.4 Thesis Outline

The thesis is composed of six sections. After section one which is the introduction, the second section will describe the background and relevance of CE. Section three reviews the theoretical framework followed by section four which reviews the existing literature about barriers and enablers of CE. Section five describes the methodology and research design and finally section six dives into the analysis and discussion of the results through the lens of IDT.

2 Background

2.1 Development of Circular Economy

The concept of circular economy dates back to the 1970s, with different schools of thought such as industrial ecology, the cradle-to-cradle theory and regenerative design (Owojori & Okoro, 2022). They explain that circular economy works towards a more efficient use of resources and advocates for their reuse to limit generated waste while adding value to existing materials and enabling economic growth. Scholars have mentioned the role of the Ellen Mac Arthur Foundation since 2012, which plays an important role in fostering research, spreading the concept and putting it into practice (Bocken et al. 2016; Owojori & Okoro, 2022).
More generally, the circular economy concept embodies an alternative economic model aimed at driving a transformative transition to achieve sustainable living within planetary boundaries (Hjaltadóttir & Hild, 2021).

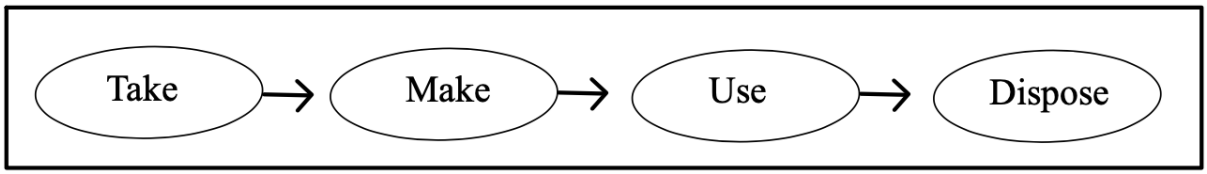

Figure 1. Linear Economic Model (adapted from Eberhardt et al. 2022)

CE is intended, as mentioned previously, to shift away from the more traditional linear economic model. As Figure 1 shows, this model consists of the extraction of resources, production, consumption and waste. Paradoxically, this model assumes that production can increase infinitely despite having finite resources (Rodrigo-González et al. 2021). Therefore, these scholars argue that the model is not sustainable anymore since human activities account for more than 50% of Earth's capacities since the second part of the 20th century. Therefore, now, the increase in resource extraction and waste is causing resource depletion and environmental damage (Rodrigo-González et al. 2021). Thus, by applying CE, industries could transition from the linear "take-make-use-dispose" model to an alternative circular model where resources are continuously recycled, reused or repurposed (Eberhardt et al. 2022, p.94).

Among the many industries approaching CE, arguably no single industry has greater importance than the construction industry. As a notoriously polluting sector, there has been a growing emphasis on making buildings more energy efficient by reducing their energy consumption when in operation (Eberhardt et al. 2022). Large efforts have been made by the European building industry to this end (Eberhardt et al. 2022). However, despite buildings becoming more energy efficient, there are still considerable amounts of construction, production, maintenance and waste of construction materials which increase the embodied negative environmental impact of the building (Eberhardt et al. 2022). They argue that CE could become a pivotal way to reduce the environmental charge of the building industry. As such, this paper will focus on material and resource conservation specifically in the structure and building phase, before the building comes into use.

2.2 The Butterfly Diagram

The Ellen Macarthur Foundation developed a diagram as shown in Figure 2, to illustrate the CE and the continuous flow of resources via a biological cycle and a technical cycle (Owojori & Okoro, 2022). This diagram shows a mirrored comparison of the industry and the environment and their apparent similarities. The authors explain that in the biological cycle, materials have their nutrients going back to the soil and in the technical cycle, the materials are kept in the cycle through recycling, reuse, remanufacturing and repair. This leads to the development of new techniques to minimize the use of resources and raw materials and therefore reduce waste creation (Owojori & Okoro, 2022).

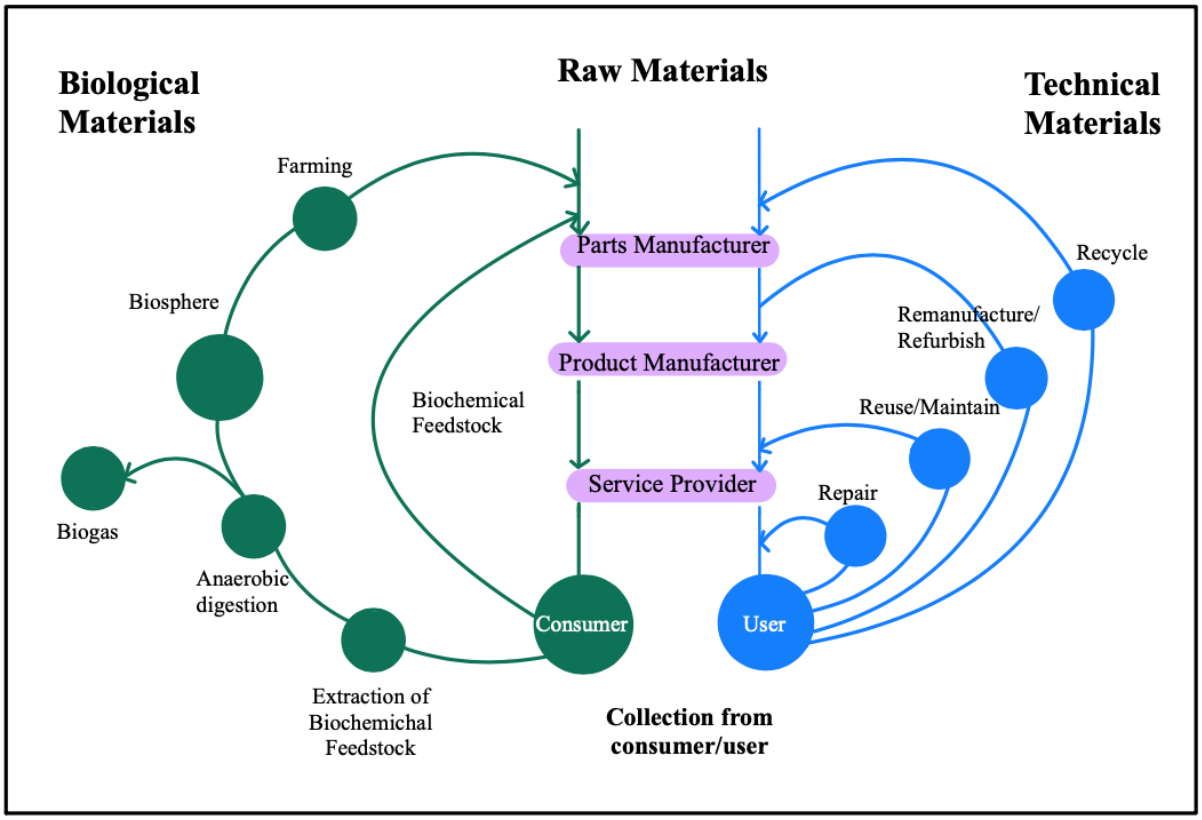

Figure 2. The Butterfly Diagram (adapted from Owojori & Okoro, 2022)

2.3 Circular Economy in Building Industry

The environmental challenges of the building industry are considerable since it was argued that the implementation of circular practices could lead to a reduction of 38% of CO2 material emissions by 2050 (Ellen Macarthur Foundation, 2022). They explain that by reducing the need for new materials, the sector would become more resilient to possible external shocks like price volatility of raw resources or sudden problems such as supply chain disruptions. Therefore, reducing the consumption of resources through new business models and technologies could greatly help to reduce emissions and waste (Ellen Macarthur Foundation, 2022; Owojori & Okoro, 2022). Furthermore, the authors add that introducing CE practices in the building sector by reintroducing materials in the supply chain allows them to gain value over time instead of being destroyed.

2.3.1 The 3R strategies

Additionally, CE addresses waste management. Indeed, a significant issue is construction and demolition waste, which accounts for about 25% to 30% of waste in the EU (Cai & Waldmann, 2019; Hamida et al. 2023). Scholars have argued that the interest in reusing material in the building sector has grown over the years and would generate economic and environmental advantages as well as the creation of new professional opportunities (Nußholz et al. 2020).

Therefore, emerging frameworks such as the 3R (recycle, reuse, reduce) are getting attention and are advocating for the re-introduction of material in the value chain and if it is not possible, materials would be recycled (Cai & Waldmann, 2019). Consequently, there is a growing emphasis on waste reduction rather than relying upon recycling, which is more costly and complex than reusing materials. Furthermore, as of today, a considerable amount of waste (estimated at 45% in the EU) ends up in landfills, leading to a loss of valuable resources and raw materials that could have been repurposed (Cai & Waldmann, 2019).

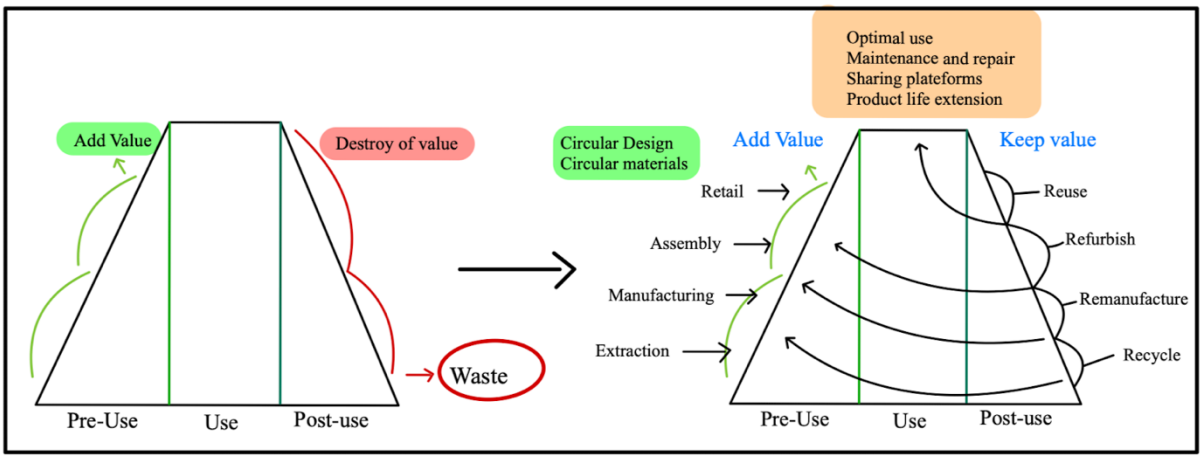

Figure 3. The Value Hill (adpated from Rodrigo-González et al. 2021)

Indeed, as illustrated in Figure 3, liner models demonstrates that all the value of the material is lost when it becomes waste. Hence, it is important to explore methods to preserve the material value through reuse, refurbishment, remanufacture and recycling depending on their quality condition (Rodrigo-González et al. 2021). Thus, the authors explain how the value hill concept can be used as a strategy tool for businesses to implement CE and think about how materials evolve during their pre-use, use and post-use. Indeed they explain that new design techniques can be developed in the pre-use phase to make components demountable and minimize waste, for example.

3 Theoretical framework

3.1 Industrial Ecology

The Industrial Ecology theory is considered the predecessor of CE and explores the similarities between biological and industrial ecosystems and processes (Górecki et al. 2019). The authors argue that this analogy between the biological and industrial ecosystems illustrates the fact that an industrial ecosystem interacts with its environment and is interrelated to many different networks because the resource availability and its uses depend on the actions of the industry. The theory promotes design processes with regard to ecological constraints and aims to optimize the resources and flow of material to imitate the function of the biological ecosystem (Jelinski et al. 1992). Therefore, waste which would have been wasted, becomes a resource for another project (Jelinski et al. 1992). Therefore, the authors explain that Industrial Ecology considers the whole lifecycle of products and aims to reduce resource extraction, consumption and pollution via new processes. It promotes the shift from the destructive linear construction industry characterized by unlimited resource extraction to new integrated manufacturing methods and designs aiming at limiting detrimental impacts on the environment (Jelinski et al. 1992). They argue that this model characterises itself with a higher flexibility than traditional linear models since it has to adapt to new limitations, manufacturing processes and new market opportunities, to foster sustainability.

3.2 Cradle to Cradle and Cradle to Grave

3.2.1 Cradle to Cradle

The cradle-to-cradle theory is a part of the broader concept of "eco-effectiveness" which advocates for a circular use of materials (Braungart et al. 2007, p.1337). Cradle-to-cradle is an alternative design style to create products with no extra CO2 emissions and aims to eliminate waste by developing a closed-loop system where materials can be recycled or reused (Braungart et al. 2007). Following along the Industrial Ecology theory, industrial products would be designed in a way that their life cycle would replicate the biological process meaning that products could recycled (Górecki et al. 2019). They explain that all the waste disappears

or is reused or recycled for another purpose. There are many advantages regarding cradle-to-cradle because it has a positive relation with economic growth in the long run as the materials are recycled or repurposed, thus adding value to materials when they are reused as they are not wasted (Braungart et al. 2007). It is explained that cradle-to-cradle also allows the creation of networks among stakeholders in the building supply chain. Indeed, old components are considered raw resources so to be repurposed, actors need to be connected to have the information about existing components (Braungart et al. 2007).

The concepts of "eco-effectiveness" and "eco-efficiency" are differentiated by the authors as one is sustainable in the long term and aims to have a fully positive impact on biodiversity and the latter focuses on short-term outcomes as illustrated in Figure 4 (Braungart et al. 2007, p.1337).

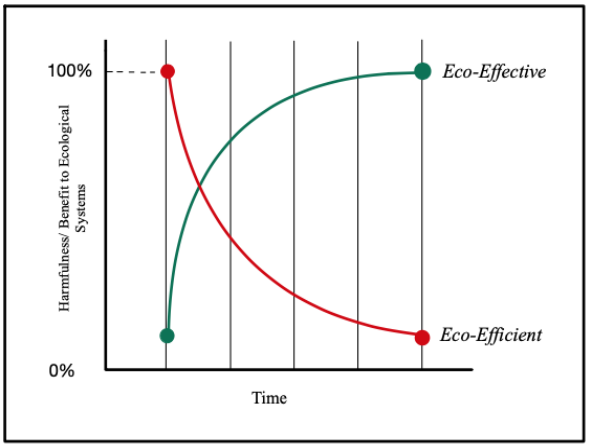

Figure 4. Eco-Effectiveness and Eco-Efficiency (adapted from Braungart et al. 2007)

The concept of eco-efficiency is a solution to minimize waste in the short term and slows down negative environmental outcomes, but it is not as efficient as the pure cradle-to-cradle or more generally, as the eco-effectiveness framework (Braungart et al. 2007). It can take the form of increasing the material quality and lifespan to make it last longer until it is not usable anymore and can qualify as waste (Braungart et al. 2007). Therefore, the less valuable parts are reused for landfill. The framework of eco-efficiency does not promote growth and innovation in the long term to the same extent as eco-effectiveness (Braungart et al. 2007). The authors add that it is because this model remains embedded in the linear economy model and does not create a framework where CE is implemented.

3.2.2 Cradle to Grave

In contrast to cradle-to-cradle, there is the cradle-to-grave model which represents the most commonly used; linear model of production (Braungart et al. 2007). In this model; resources are thrown away after their use rather than being recycled or reused. Therefore, this model has important negative consequences whether it be social, economic or environmental because it leads to resource depletion and pollution (Braungart et al. 2007).

3.3 Innovation Diffusion Theory

Another theory that the paper will use is the Innovation Diffusion Theory (IDT) invented in 1962 (Wonglimpiyarat & Yuberk, 2005). The authors explain that this theory is used to explore the reasons behind the diffusion of innovations over time and how they diffuse in a social system. It is important to note that the term innovation refers to ideas, technologies or products (Roger, 1983). In IDT, theories from communication, sociology and psychology are used to draw links and explain the root causes of innovation diffusion (Wonglimpiyarat & Yuberk, 2005). Indeed, Roger (1983) explains that the innovation diffusion and adoption of an idea is a complex process which involves societal choices and cultural willingness to adopt it. Roger (1983) explains that the theory is framed around 4 elements which are the development of the innovations, the social setting in which the diffusion proceeds as well as the the communication channels through which the information is disseminated and finally, the time frame of the innovation development. Rogers (1983) also argues that the rate at which an innovation is adopted is influenced by several independent variables as illustrated in Figure 5.

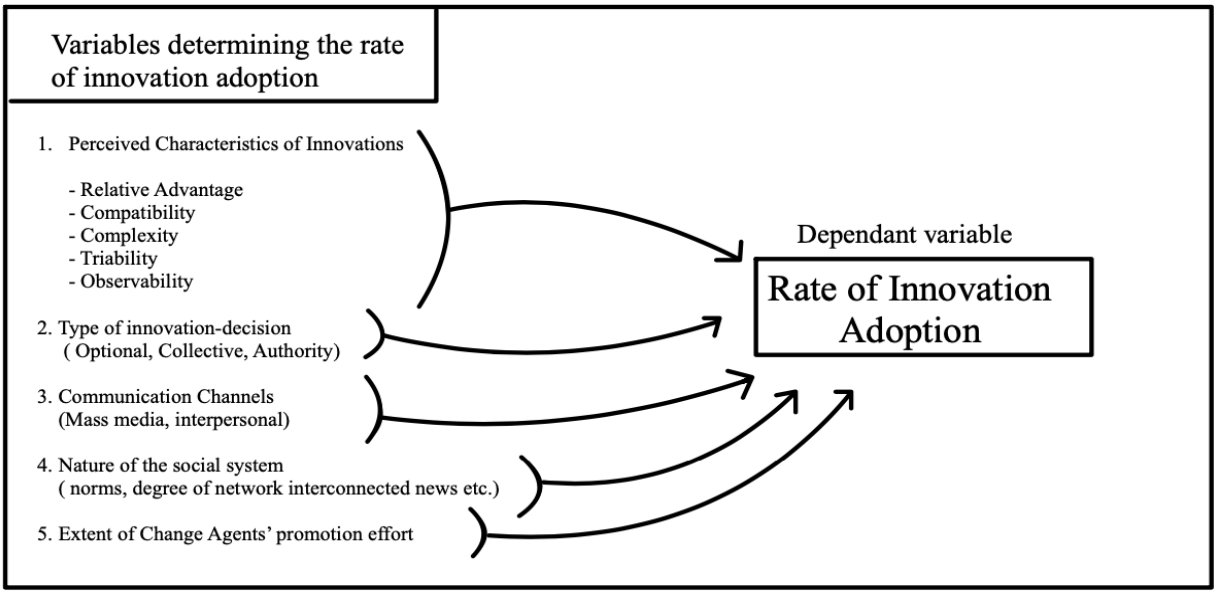

Figure 5. The rate of innovation adoption (adapted from Rogers, 1983)

Rogers (1983) describes the five perceived characteristics of innovation on which the paper will mostly focus on out of all attributes and they are explained below.

- The *relative advantage* refers to the relative degree at with an innovation is perceived to be better compared to its predecessor, or with the additional benefits it offers and is positively correlated with the innovation adoption rate (Rogers,1983).

- *Compatibility* refers to the degree at which the innovation aligns with the values and beliefs, previous ideas as well as the needs of clients and potential adopters. Therefore, if an innovation is compatible, it will be considered less risky for the adopter and is therefore positively related to the adoption rate (Rogers,1983).

- *Complexity* illustrates the perceived degree at which an innovation is difficult to implement, use or comprehend and is therefore correlated negatively to the innovation adoption rate since it slows down the process (Rogers,1983).

- *Triability* refers to the extent at which an innovation can be tested on a small scale and it is positively correlated with the adoption rate. Indeed, ideas have more chances to be adopted if they can be easily tried (Rogers,1983).

- *Observability* refers to the extent at which the outcomes of an innovation are apparent to others and it is positively associated with the adoption rate since it can fasten the innovation diffusion (Rogers,1983).

These five characteristics are said to explain between 50% to around 90% of the rate of innovation adoption variance, making them important to take into account (Roger, 1983).

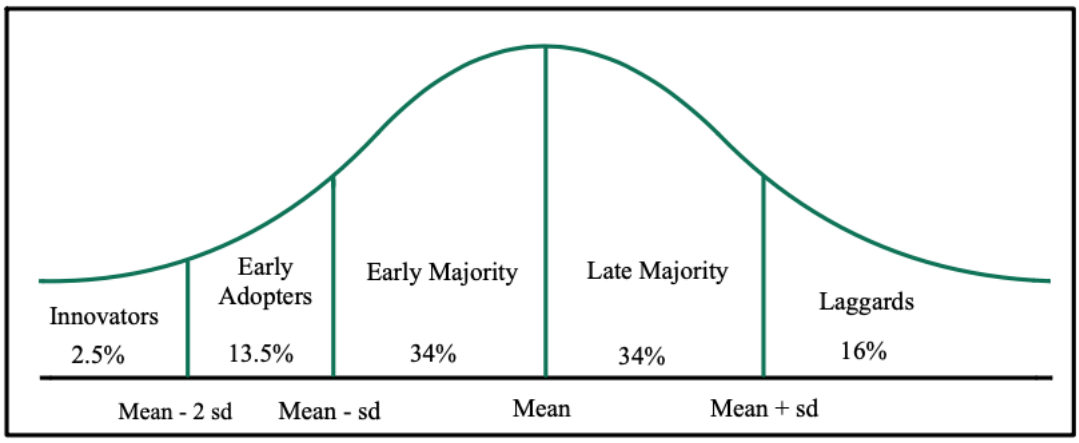

Figure 6. The types of adopters (adapted from Rogers, 1983)

As illustrated in Figure 6, IDT also establishes 5 categories of adopters which are the innovators, early adopters, early majority, late majority and laggards. The innovators are the first to adopt and experiment with novelty because they have a higher capacity to handle risk (Roger, 1983). Furthermore, communication among early adopters differs from late adopters as they are more inclined to acquire new knowledge about innovations, promote social interactions and are more deeply integrated into social networks (Rogers, 1983). The author also argues that innovators tend to be larger companies or industries with specialized operations since they have more resources to take risks. Then, innovators are followed by the early adopters, who can be considered opinion leaders since they shape public opinion by finding more advantages in adopting the innovation than in not doing so (Dearing & Cox, 2018; Rogers, 1983). The scholars explain that after comes the early majority, late majority and laggards as they are influenced by the rest and feel the need to adopt it.

In IDT, the distribution of adopters also takes the form of an S-shaped curve as illustrated by Figure 7 and it is explained by the *diffusion effect* which is defined as:

> the cumulatively increasing degree of influence upon an individual to adopt or reject an innovation, resulting from the activation of peer networks about the innovation in the social system (Rogers, 1983, p.269).

Indeed, the diffusion effect explains that in highly interconnected networks, innovation will be diffused faster (Roger, 1983). Therefore, the degree to which other individuals are influenced to adopt the innovation will be lower if only 10% of people are aware of the idea compared to 90% (Roger, 1983). The author further argues that norms regarding innovation evolve over time as the diffusion process advances.

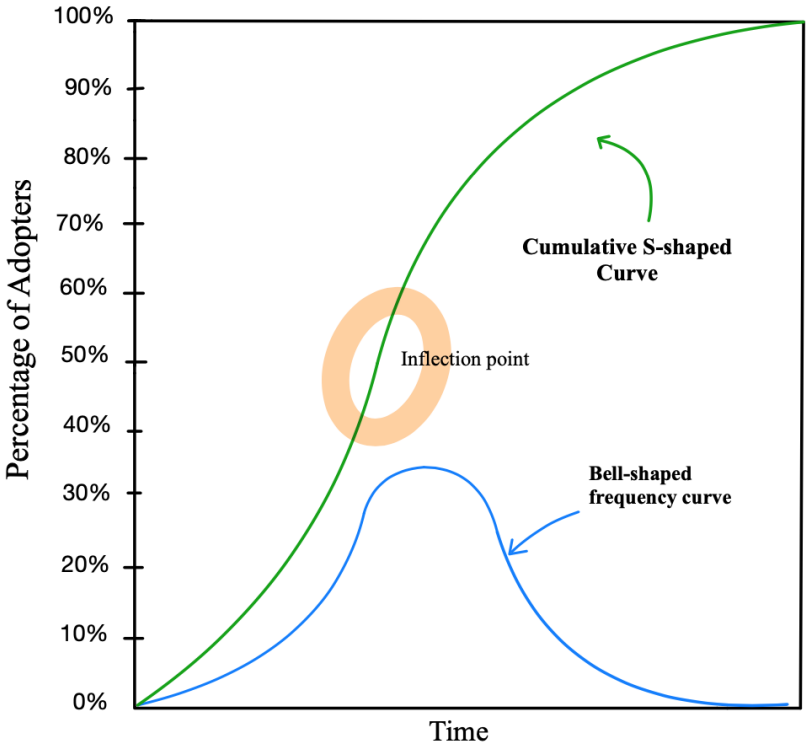

Figure 7. The distribution of adopters by the s-shaped cumulative curve and bell-shaped frequency curve (adapted from Rogers, 1983)

The bell-shape and cumulative s-shaped curve, illustrated in Figure 7, explain the diffusion of innovations among adopters over time. This curve is characterized by a slow rise at the beginning due to low adoption rates, which then accelerates when about 50% of individuals have adopted the innovation and then slows down as the adoption rate decreases (Roger, 1983).

The bell-shaped curve illustrates the innovation adoption each year by individuals and the S-shaped curve shows the same information but in a cumulative way (Roger, 1983).

4 Literature review

The literature about CE in the building industry is scarce but it has been increasing in the past years recently because the topic is getting more attention about the ways of going from a linear to a circular model (Hjaltadóttir & Hild, 2021). The literature emphasises the necessity of all stakeholders to engage and collaborate with each other to make the industry sector more circular and that both public and private sectors need to adapt their operations accordingly (Owojori & Okoro, 2022). Yet as outlined in the literature, this transition faces numerous barriers to adopting CE which includes regulatory, financial, sectoral, and cultural challenges (Hart et al. 2019).

4.1 Role of the Public Sector

4.1.1 Lack of Regulations Hindering CE Development

The role of the public sector is crucial in driving change towards CE practices by putting in place frameworks through regulations and policies (Hart et al. 2019). Unlike the profit-driven private sector, the public sector pursues more social and political objectives, such as resource redistribution, policy development, and provision of public services (Owojori & Okoro, 2022). However, the lack of involvement of the public sector is a major obstacle hindering the development of CE in the building industry (Hart et al. 2019).

Indeed, these scholars argue that given the interconnectedness among stakeholders and the overall complexity of the industry, implementing regulations and policies is essential to create change in this industry. Scholars agree that there is a lack of consensus and defined targets necessary for effective implementation (Hart et al. 2019). Furthermore, the authors argue that regulatory hurdles such as anti-trust laws and waste management regulations impede CE and constrain collaborations among firms.

4.1.2 European Union Initiatives

Some scholars have examined how international organisations like the European Union can drive change. Górecki et al. (2019) noted the creation of the circular economy action plan by the European Commission to encourage a shift to CE practices. Bocken et al. (2016) underscore the willingness for the commission in bringing the focus to limiting material loss, increasing recycling, creating new employment opportunities in the field of CE and helping businesses move towards lower greenhouse emissions and zero waste. Górecki et al. (2019) also proposed for the commission to create an investment fund for circular projects as a solution to minimize the risk associated with circular construction projects and investments. Overall, it can be said that the public sector is an indispensable part of the transition to CE, but has nonetheless become insufficiently involved as of today.

4.2 Role of the Private Sector

According to the literature, the private sector plays a major role in driving change towards CE initiatives (Owojori & Okoro, 2022). These authors highlight the literature gap in understanding the specific roles that the private and public sectors play in CE as well as their own barriers, indicating a need for further research. The private sector being more flexible and eager to take risks, in stable economic conditions, has developed most innovations and implementations of circular practices (Owojori & Okoro, 2022). Additionally, adopting CE practices can confer a competitive advantage and marketing power of showcasing projects with lower carbon footprint (Górecki et al. 2019). Furthermore, there is a lack of trust of the secondary materials quality. Some authors argue that to counter risk, insurance schemes could be developed on reused materials to combat risk perception (Circuit, n.d).

4.2.1 Financial Incentives

Moreover, financial concerns represent an important barrier to the diffusion of CE. The progression of CE faces numerous hurdles, including substantial initial expenses for developing reverse logistics, material certification, and pre-construction research and design (Hart et al. 2019; Nußholz et al. 2020). Consequently, transitioning to a more circular construction sector demands substantial investments (Owojori & Okoro, 2022). However, the

lack of involvement from institutions and regulations represents a main barrier that hinders the private sector from engaging in CE (Owojori & Okoro, 2022). The authors adds that the lack of investments emanates from most stakeholders focusing on profitability, hindering the development of sustainable projects.

Today economic models do not prioritize sustainability as the focus is on profit maximization and less on social returns and economic well-being (Rodrigo-González et al. 2021). Therefore, these authors emphasise the need to develop sustainable finance to drive change. However, they mention that it is a field currently restricted and constrained and would require both the involvement of the public and private sectors to go forward with new business models and sustainable finance solutions (Owojori & Okoro, 2022).

4.2.2 New Business Models

As the construction industry is traditional and highly standardized, it is challenging for companies to implement CE and therefore there is a need to adjust the business models for their economic viability (Nußholz et al. 2020). CE is difficult to implement due to the lack of regulations and standardization making it difficult to recover material (Hart et al. 2019). They argue that due to the complexity of the industry and fragmented supply chains, the building industry has been described to be adverse to change. Therefore, some scholars, highlighted that business change would need to adopt new ways of managing waste, restructuring organizational methods and supply chains to go towards a more loop-system (Górecki et al. 2019). Regarding the strategies, many different types of business models are highlighted to decrease resource use (Bocken et al. 2016). The authors mentioned either slowing processes via designing long-lasting products or further closing the loop to extend the resource value via design for disassembly or other designs, meaning that the components and waste can be safely recycled into making new materials. There are multiple examples of companies that adapted their business model to go towards circularity such as the Danish architecture firm Lendager, with one of their building; the Ressource Row for example, made with old bricks, saving 400 tonnes of waste (Langer, 2023).

Furthermore, to address regulatory barriers hindering the development of CE, a restructuring of the roles of certain businesses is needed. It is advocated that suppliers and producers could

take on more responsibility by specializing in the supply of reused materials which could be possibly supported by tax incentives like VAT reductions (Hart et al. 2019). However, this idea is endorsed by contractors but is not favoured by producers, highlighting the lack of consensus among stakeholders (Hart et al. 2019). Therefore, these scholars argue that implementing CE practices necessitates significant investment from participating stakeholders, making it challenging to reach consensus due to differing visions and knowledge levels which can influence their willingness to participate in CE (Hart et al. 2019).

The authors Owojori & Okoro (2022) illustrate the potential where the private sector can play a role in addressing such as reusing old buildings to repurpose them into buildings with a different purpose from what they were originally built for such as transforming a hotel into an office space and is called "adaptive reuse" (Owojori & Okoro, 2022, p.14). Therefore, the authors explain that the private sector can reevaluate their business model to be aligned with new integrated supply chains and to increase collaboration with other companies and stakeholders to enhance circular practices.

4.2.3 Material Banks to Increase Transparency in the Market

Furthermore, digital platforms can help increase the transparency in the market over the availability of resources to make them more visible as well as helping to "close the material loops" (Çetin et al. 2022, p.10). Literature is emerging about material banks which are digital marketplaces of secondary materials which can either be physical or online (Cai & Waldmann, 2019).

Some scholars explain that an existing building is technically a material bank since all the components already exist and are waiting to be either refurbished or dismantled to be used again and put back in the value chain, this is called "urban mining" (Çetin et al. 2022, p.2).

However, to upscale the use of reused materials, the best strategy has been argued to have digital material banks as they give an overview and easy access to what is available in the market (Cai & Waldmann, 2019). In doing so, material banks can help overcome a key barrier to CE in construction which is the mismatch between demand and supply of materials within a short time window and it leads to risks of delays or unavailability of materials (Circuit, n.d).

Therefore, digital material banks are argued to be crucial in matching the demand and supply of secondary materials and are also easy to put in place with little investment (Çetin et al. 2022). Indeed, the authors explain that inventories are made during the demolition process and this information on material availability can ease the design process to have a material cycle and thus, less waste. Furthermore, to upscale the reuse of materials, these authors mentioned the importance of network effects to further develop these online platforms. Indeed, the more suppliers and users join the platform, the more material will be available, therefore making these material banks more attractive and successful in driving change on a bigger scale (Çetin et al. 2022).

4.2.4 The Potential of BIM

Furthermore, to enhance the transparency about the availability of materials, scholars have argued that traditional tools like BIM (Building Information Modeling) have untapped potential to be used for circular practices (Hart et al. 2019; Sudarsan & Gavali, 2024). BIM is a tool used to create a 3D version of buildings and therefore can be used to assess the specific amount of materials that a building needs as well as easing its maintenance by following the building's lifecycle (Sudarsan & Gavali, 2024). Therefore, the authors argue that the underexplored capabilities of this tool could be used in CE to reduce waste by optimizing resource use, reducing design errors to ease deconstruction and therefore reducing the carbon footprint.

As an example, a report by Sweco (2022) mentioned a tool called *Twinfinity* which is a circular BIM and aims to create and renovate buildings to make them better adjusted to the needs of the inhabitants, thanks to the collection of data about financial information, behavioural and usage patterns. This would therefore reduce waste, unnecessary costs and environmental impacts (Sweco, 2022). This report further explains that due to complex supply chains and lack of collaboration in the industry, having all information of building standardized such as certain costs, resources and material availability or even energy consumption can greatly increase transparency and develop circular practices.

More scholars agree with the benefits of BIM, material passports which contains all information about the component, and other methods to assess the possibilities of reusing structures (Hart et al. 2019). These new technologies have a lot of potential to bridge the gap between the different barriers, especially having matching supply and demand to have more visibility on when materials are available (Çetin et al. 2022). Meanwhile, scholars showed that some professionals in this industry are reluctant to use new technologies and are adverse to change, digital tools and online marketplaces are considered to represent great opportunities in easing the development of CE (Hart et al. 2019). The main barrier is that not enough professionals know about these tools and their potential which hinders CE development (Çetin et al. 2022).

4.2.5 Design for Disassembly

In the aforementioned study by Bocken et al. (2016), it was argued that business models, and specifically their associated design processes need to change and adapt from a linear to a circular model and specifically explains Design for Disassembly (DfD). DfD is a design technique made to easily disassemble and reassemble structure parts and preserve the material quality so they can be reintegrated into the value chain (Bocken et al. 2016). Therefore, DfD is considered an important tool to facilitate 3R processes as materials parts can be easily separated and sorted out (Cai & Waldmann, 2019). Furthermore, DFD and more standardised materials can enable more flexibility for designing future buildings and ease their deconstruction (Eberhardt et al. 2019). The Circle Houses in Lisbjerg as an example, is a project of 60 houses designed for disassembly, as 90% of the components can be disassembled and reused (GXN, 2018).

The lack of recycling and reuse of construction waste can be attributed to insufficient policies, guidelines, regulations, material quality assessments, and lacking knowledge about reusing components (Cai & Waldmann, 2019). It is also highlighted that there is a good amount of literature about recycling techniques but a lack of research on how to assess the quality and chemical presence in reused materials (Cai & Waldmann, 2019). Therefore, the authors argue that material banks and new design techniques can make the reuse of materials safer for them to be reintegrated into the supply chain, fostering sustainability in the construction industry. Furthermore, to reduce material use, DFD is one of the most frequently discussed tools in the literature for circular buildings (Eberhardt et al. 2022). However, some scholars have pointed

out that there is less focus on the maintenance and repurposing of buildings, which they argue should be given more importance (Çetin et al. 2022).

Therefore, digital platforms and tools offer a range of opportunities to facilitate circular construction in an industry, characterized by complex supply chains and a lack of knowledge about digital tools (Çetin et al. 2022). More generally, the current literature available on digital tools is optimistic and shows that they can play a major role in implementing CE. However, due to a significant lack of real-life case example, existing studies of circular construction remain largely theoretical (Çetin et al. 2022). Therefore, these scholars argue that more case studies are needed to understand how CE practices are implemented, identify challenges, and determine where digital tools can be effectively utilized. It has also been stated that the literature focuses more on architects, engineers and demolition and waste professionals but little emphasis has been given on actors such as real estate professionals or property managers who have strong market power and could greatly accelerate the development of circular practices (Çetin et al. 2022).

In summary, the private and public approaches to CE are in some ways mirror images of each other. The roles of the private and public sectors are interrelated and codependent as they both need to implement solutions to develop circular practices. Therefore, scholars advocate for a dual approach to integrating CE with a macroeconomic perspective (Górecki et al. 2019). They firstly point out the need for vertical integration from international organisations, countries, national investments, regulations and policies. Therefore, companies would see the potential of investing in CE and would have safeguards against potential risk (Górecki et al. 2019). Thus, they have argued that horizontal integration would follow, consisting of CE implementation within specific industries and sectors. The main driver of innovation adoption is financial stability so therefore, providing a framework would mitigate perceived risks and incentivize companies to adopt CE (Górecki et al. 2019). Therefore, they show that the role of the public sector is essential to help and procure an environment to help the private sector develop CE and ensure the respect of competition and protection of natural resources.

5 Methodology

5.1 Qualitative study and Semi-Structured Interviews

To guide the analysis and discussion, an main assumption was framed: *The rate of diffusion and adoption of Circular Economy (CE) practices depends on perceived risks*. Indeed, to enhance organization and clarity, four sub-assumptions were formulated in the discussion. They serve to highlight key concepts and are analysed within the framework of Innovation Diffusion Theory (IDT).

- Sub-assumption 1: The lack of regulations is hindering the diffusion of circular practices as risk is not mitigated

- Sub-assumption 2: Financial incentives and lower prices are essential for encouraging the adoption of circular practices among construction firms, as they help mitigate risk perception

- Sub-assumption 3: Digital tools and new technologies are solutions to increase transparency and mitigate risk and increase the rate of adoption

- Sub-assumption 4: More interconnected networks and knowledge enhance the diffusion of circular innovations in the construction industry and can mitigate risks

To answer the research question, a qualitative research method was adopted. Semi-structured interviews were conducted, which also compensates for the lack of interviews about circular buildings highlighted in the literature (Owojori & Okoro, 2022). As the topic was specific, running semi-structured interviews instead of structured or unstructured was the most suited choice because the ideas and opinions could be explored further in depth but still stay in a certain frame (Bryman, 2016). Indeed, questions were asked and there would be follow-up questions based on the answers, which was a more flexible way to explore the topic thoroughly (Bryman, 2016).

Conducting interviews was more appropriate for my topic research since it is about different perceptions and in-depth knowledge about circular practices and their diffusion. Therefore, using qualitative surveys for examples would have not been as suited because less argumentation is possible. Therefore, conducting interviews allowed the analysis of real business cases as well as taking into account the opinions of different stakeholders, therefore enriching the current body of research.

5.2 Data Collection

To conduct this study, eight individuals from different professions were interviewed.

The interviewees:

- A lead architect of the Brunnshög district in Lund Kommun in Sweden
- An architect and lead project manager of the Brunnshög district in Lund Kommun in Sweden
- A sustainability expert working at Lund Kommun in Sweden
- A consultant working with digital tool development to ease circular practices in the building industry in Sweden
- An architect working with circular practices and material bank working in Denmark
- A Head of Sustainability at a Swedish real estate company
- A PHD in Material Sciences from Lund University now working in a construction company in Sweden
- A Sustainability expert working in a Swedish construction company

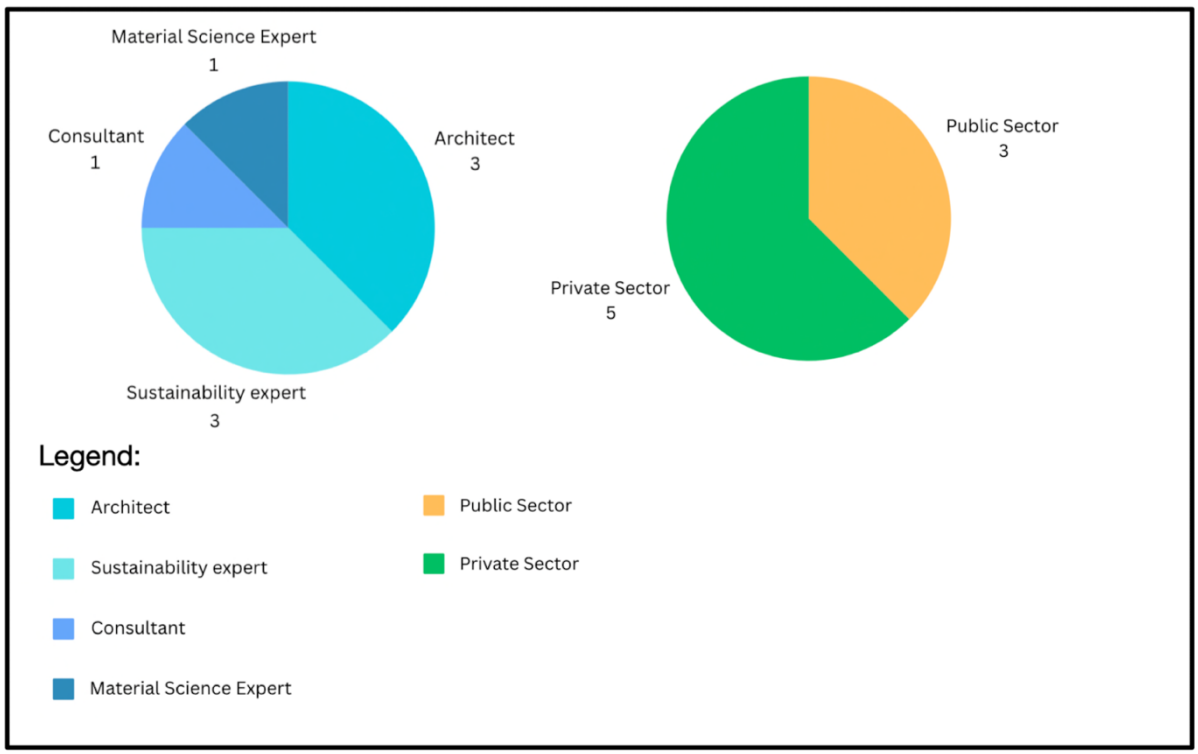

Figure 8. Composition of the interviewees. Illustration by the author

During the data collection process, 18 requests for interviews were sent and 8 respondents answered positively. The people in academia were the hardest to reach out compared to the other ones. However, their opinion was heard through a discussion panel about circularity in the building industry organised as a part of the sustainability week in Lund. Unfortunately, no interviews were conducted during that event. In total, 7 interviews were conducted between the 26 of March 2024 and the 3 of May 2024, including one with 2 individuals. They were all conducted in English and lasted between 45 min and 1h30 min. Furthermore, 5 interviews were conducted online and 2 in person. These interviews were recorded, transcripted with the program Whisper and the form of consent for data collection, study aim and conditions was sent to all interviewees.

Due to the diversity of participants' professions, it was highly interesting and relevant to have their opinions since the circular economy principle involves all stakeholders in the industry. It was interesting to have different perceptions about this topic depending on the knowledge level of the interviewees and their investment in CE practices.

5.3 Data Analysis

After collecting the data, the content was analysed to identify the main recurring themes and patterns, which were then sorted into different categories upon my operationalization and questions inspired by the method used in Hjaltadóttir & Hild (2021). This eased the comparison of results between the findings from the literature and the participant's answers. However, while the smaller size of the study has its limitations, it also allowed a deeper analysis of each individual participant. This is why a more rigorous interview coding in the style of Hjaltadóttir & Hild (2021) was not applied. The main themes identified were among other:

- The advantages of CE
- Barriers hindering progress
- The role of public and private institutions
- Risk perception of CE
- Role of new technologies to drive CE
- Cooperation
- Future of CE
- New business models
- Ideas of incentives

The results were analyzed through the lens of IDT principles, specifically focusing on the *perceived characteristics* influencing the innovation adoption rate, as mentioned above, and how participants perceived them within the context of CE diffusion when it was applicable. The remaining characteristics influencing the rate of innovation adoption, as previoulsy illustrated in Figure 5, were also used such as communication channels or nature of the social system, but to a lesser extent. Additionally, as it is a new field, this paper can only focus on the early part of innovation adoption and try to see the varying perceptions and ideas that could further diffuse CE.

5.4 Limitations

Given the qualitative analysis approach adopted in this study, it is important to acknowledge that the findings from the interviews cannot be generalizable and representative of all building circular practices globally as it is also context-specific to Denmark and Sweden. Furthermore, the exploration of the topic cannot be thorough due to the small amount of seven interviews. In addition, there is inherent bias since the results are influenced by the individual's experiences or willingness to present themselves as more involved in sustainability as well as bias due to the researcher's preconception of the topic with previous research. This study also focused on specific cases and didn't dive into all aspects of circular economy in the building industry. There is also a lack of interviewees working in Denmark, especially in the Danish public sector as only one architect was interviewed, which creates bias and does not represent fully the concerns in the country. Furthermore, using IDT also presents some limitations since this theory is general and does not focus on the constructing sector per se.

6 Analysis and Discussion

This section will analyse and discuss the results of the interviews throught the lens of the IDT.

6.1. Discussion of the results

Circular practices in the built environment have been gaining a lot of emphasis during the last ten years. All interviewees agreed upon that is a fast-moving field and that now the knowledge of what is on the market is much more clear. Indeed, the interview results showed that fifteen to twenty years ago, it was just some innovators but now, there has been a multiplication of projects mostly located in the Netherlands, the UK, Denmark and Sweden, which are the pioneers in the fields.

Categories of innovators

In line with IDT, the participants actively working with CE represent the innovators and early adopters because they showed in their answers that they were willing to take on more risk. Two interviewees; one architect and one consultant, argued that the main objective is to experiment and learn about new processes to drive change even if some projects were more costly than

traditional construction. Small companies are important drivers of innovation but as mentioned in the interviews, larger construction companies and architects firms, both in Denmark and Sweden, are developing some circular practices into their scheme. For some, it is at an experimental level and for others at more mature processes. This is in line with the IDT theory that larger companies can take more risk since they are more financially stable and therefore can invest to have a department for sustainability. As an example illustrated in the interviews, a Swedish construction company took on the project of a circular building by reusing concrete panels to build an office in Karlskrona, in Sweden. They said it was expensive but they learned a lot by doing it as explained by an interviewee working in the construction sector.

On the other hand, some results highlight that it is also challenging for big companies to innovate because it can be more complicated for them to change their practices since the construction industry is complicated, highly standardized and has supply chains only adapted for linear practices. The process involves also many stakeholders who are pushing their incentives in different ways.

General perceived relative advantages of CE, according to IDT

All interviews agree upon the perceived advantages of circular practices in the building industry and the findings are in line with what is found in the literature, which further consolidates it.

They argued that the relative advantages of CE, according to IDT, are environmental and economic benefits. Limiting resource depletion was a main argument as well as CO2 reduction and learning how to use resources in smarter ways. As highlighted by the consultant interviewee, it allows companies to have better control over the supply chain and be less exposed to risks since linear are often international. If something goes wrong, it will have important repercussions on the lower supply chain. The interviewees active in CE further argued that circular practices allow an active tracking of all the components present in buildings, therefore, keeping it as a dynamic asset evolving over time. This eases the possibility of reusing material rather than destroying it as linear models would, which simultaneously increases their value over time. It is in line with the value hill model as well as the concept of eco-effectiveness aforementioned in the paper. Furthermore, some interviewee argued that CE

practices allow one to become aware of the values present in materials and of their embedded CO2. Another relative advantage of CE was mentioned by an interviewee working in a construction company who highlighted the fact that employees are more motivated to work with circularity and sustainability projects because they feel like they are helping make a change.

Continuing the analysis, four sub-assumptions are discussed below according to IDT to address the main ideas about CE linked with the interview results.

Sub-assumption 1: The lack of regulations is hindering the diffusion of circular practices as risk is not mitigated

Through the lens of IDT and consistent with the literature, all interviewees mentioned that the lack of regulations increases the perceived complexity of putting in place circular practices. Therefore, they argued for the benefits of having regulations and policies, emphasizing that these are needed to create a framework for companies to evolve with clear goals, incentives, and constraints.

Indeed, the market is coordinated by demand pulls and pushes so the role of the public sector is important to set the framework and encourage companies to implement CE practices. As of today, there are some public initiatives like the European circular action plan, in line with Górecki et al. (2019), but interviewees argued that it was not enough since there are no regulations implementing circular practices. As regulation examples, an interviewee argued for making mandatory the use of a certain percentage of reused material in a new building, and there would be penalties for non-compliance. This could be a solution for traditional construction companies to start learning, and handling reused materials. He argued that it does not represent too much risk if they incorporate only 10% of reused materials rather than incorporating 80%, which would not be feasible as of today. The interviewee argued that starting step by step was necessary to spread knowledge within companies, as explained by IDT.

Furthermore, another parameter that increases the perception of complexity to shift to CE is the highly standardised characteristics of the building industry. This could explain the

argument brought up in the literature that the construction industry is adverse to change (Hart et al. 2019). It is in line with IDT as the building industry is defined by traditional ways of operating and strong norms. Therefore, two interviews also mentioned the ineffectiveness of some regulations like the specific building permits that are now being used. Indeed, they argued that their specificity such as a special brick color is hindering circular practices because every detail has to be approved a long time before constructing the building. Therefore, to create a building, materials can be secured to suppliers years in advance. However as the industry is currently not adapted for CE, it is difficult to know which material will be available in a long period. Indeed, nowadays the availability of reused materials is not reliable and highly changeant since all the supply is not known and components can't be kept for a long time as they are expensive to store. Therefore, the constructor cannot be sure to have the specific type and colour of brick needed in the future. So to bypass this regulation slowing down the development of CE, these participants advised for more flexible building permits to adjust the supply to the demand more quickly, especially when characteristics are not vital for the building such as when it comes to aesthetics. However, another interviewee argued that this matter of building permits was too much talked about in the debate because it would be easy to change and is not the main issue. Therefore, an important barrier highlighted from the interviews is the difficulty of adjusting the demand and supply in short deadlines.

The observability and trialability characteristics of IDT, are not applicable in this part since no regulations to implement CE have been put in place as of today in Sweden and Denmark. Two interviewees talked about a regulation to increase overall sustainability in buildings in Sweden and Denmark, consisting of a certain CO2 threshold per square meter. However, they mentioned that this developing regulation was not challenging enough to create change.

Therefore, regulations could importantly impact the rate at which innovations are adopted. In this case, the lack of CE regulations importantly slows down the rate at which circular practices are diffused in the building industry.

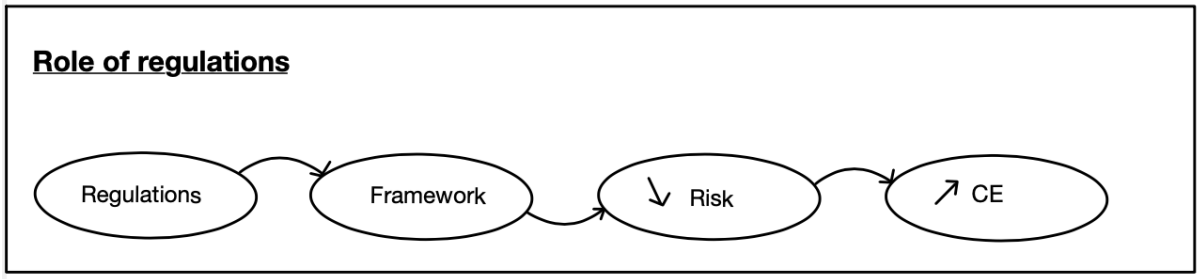

Figure 9. The potential role of regulations to mitigate risks. Illustration by the author

Sub-assumption 2: Financial incentives and lower prices are essential for encouraging the adoption of circular practices among construction firms, as they help mitigate risk perception

The lack of sufficient sustainable investments represents a significant barrier and contributes to the increased perceived complexity of transitioning to circular practices, as mentioned in (Rodrigo-González et al. 2021).

Nowadays, as mentioned in the interviews, it is more expensive to build with reused materials than with new ones because reused materials do not have a price index nor have their own mature market yet. Many interviewees mentioned the high cost of reusing materials due to the need to hire specialists to seek hazardous chemicals and assess the quality and safety of the material to get the CE certification. Therefore, it is a main barrier because as mentioned by Hjaltadóttir & Hild (2021) and two interviewees, when a new building needs to be constructed, there is a competition between projects and usually, the cheapest one wins. So, as constructing with circular materials is more expensive, it is not attractive for clients. Some interviews stated that nowadays, more clients put a bigger emphasis on sustainability and are willing to pay more. However, in general terms, the high prices remain one of the most important barriers hindering circularity.

As a part of a solution to this problem further spread CE, some interviews argued that there is a need to put more emphasis on the role of suppliers for them to certify the quality of product and take responsibility for the risk. This argument is in line with Hart et al. (2019). Two interviewees exemplified *Brukspecialisten* which is an innovator in the field of reused materials since this swedish company specializes only in the refurbishment and selling of secondary bricks. Therefore, the interviewees argued that reused materials have to come from the suppliers because then, they can have standardized techniques to assert the quality and remove

chemicals. They can test their quality which lowers the costs of materials due to economies of scale and specialization. In that way, suppliers bear the risk by assessing the quality and therefore contributing to risk mitigation.

As a part of the observed complexity; one of the participant architects explained, that it was highly complicated to get funding for the projects namely The Resource Row and Row Houses located in Copenhagen as investors thought it was too much of a risky project. This is in line with Owojori & Okoro (2022) stating that the lack of involvement of many stakeholders is explained by the objective of having profits in the short term and not the long term. Therefore, all of the financial barriers cited reveal some complexities that are slowing down the development and diffusion of circular practices.

However, some solutions exist such as the development of green bonds and the developing idea of establishing risk funds. Indeed, some interviewees talked about the role of the EU taxonomy that will soon regulate how financial institutions manage their investments and will have to report how sustainable they are. Therefore, it was argued that it will create an important incentive for building owners to build more sustainably because it will be easier to get loans with better interests. Therefore, some interviewees have hope that thanks to these incentives, these circular projects are likely to be cheaper, attractive for investors and more profitable.

To mitigate the risk perception of CE, an interviewee also talked about the potential development of risk funds. Therefore, clients would likely be more willing to adopt CE practices because they would be assured again potential risk and money loss. Indeed, the interviewee added the main problem is not working with the materials but it is how to mitigate risk perception.

Therefore, participants argued for the need to have financial incentives such as green bonds which are already implemented and can be related to the observability attribute of IDT. They also argued for tax reduction for owners that refurbish a building or higher taxes on waste production. These measures could develop incentives for stakeholders to invest in sustainable projects which would therefore increase the rate of diffusion of CE.

Therefore, if sustainable finance and risk funds were more developed, the risk would be mitigated and it would most likely fasten the rate of adoption and diffusion of circular practices

in the building industry. However, as these measures are lacking today, it slows down the rate at which circular practices are adopted, which in line with IDT.

Sub-assumption 3: Digital tools and new technologies are important to increase transparency and mitigate risk and increase rate of adoption.

Regarding new technologies, four interviewees talked about the relative advantages of material banks. They agree with the literature by arguing that the development of material banks on a big scale would increase transparency over the material available on the market, in line with Cai & Waldmann (2019). They argued that more stakeholders would be convinced to use old materials if they were certified and easy to access. One architect interviewee mentioned the project Varvsstaden in Malmö ,in which she was involved into creating Material Banken, which is the place, on-site, where all materials are inventorised and stored. The interviewee explained that in line with IDT, the learning curve was important for Varvsstaden since the process of using and developing the material bank became easier with time.

The only drawback that she mentioned is that this project is quite unique in itself as it is a closed-loop so therefore not scalable since all materials are reused on the site only. Some interviewees talked about the development of online platforms, in line with the literature review, that are in different stages of development or the ones that are ready are not widely used yet. They argued that these platforms have important potential and that this innovation is diffusing fast. One interviewee talked about a Danish company material bank platform and argued like other interviewees, that digital material banks are essential to upscale the use of reused materials because all of the pieces of information are available online to all stakeholders and easy to access. She explained that the Danish platform is also capable of helping manage used materials in a smarter way as it can assess the carbon embedded in the material. Therefore, a material with more embedded CO2 has more value to be reintegrated in the supply chains since it took a lot of energy to produce it. Thus, in a building that will be demolished, it is possible to identify the most valuable components, the ones with the highest value. Regarding material banks, other interviewees talked about *CCbuild* which is a Swedish material marketplace for secondary materials that also needs to be developed further since it is now used for small components and not for bigger ones like concrete frames for example. These tools have been experimented with and tried, which is in line with the triability attribute

of IDT. Some new processes like material banks are getting increasing attention as mentioned in the interviews that Varvstadden has one awards for their projects, and that CCbuild is known in the building industry sector, which is in line with the observability attribute of IDT.

Hence, according to IDT, the key advantage of digital tools lies in their capacity to facilitate the scaling up of material usage for semi-closed loops or increased material utilization, even if they do not necessarily achieve closed-loop systems. This is also in line with the aforementioned industrial ecology theory.

One interview explained the potential of BIM used to model buildings in 3D. As previously mentioned by Sweco (2022), the interviewee mentioned the BIM tool *Twinfinity* and explained that BIM can be expanded to many more capabilities than it is used today to ease processes in circularity and help to manage assets as it can do an inventory of what is available in the building. Therefore, the interviewees argued that these tools can help overcome barriers hindering CE as can be used to identify components to ease the inventory of material banks or to have a proactive digital copy of a building to see if elements have changed over time.

They explained that they can also be used to overcome storage issues when they are further developed since they are at the innovation stage now. It was argumented that through machine learning and depending on different variables such as the age of the building, function, crime rate and more, it could be predicted over a few years when a building would be demolished. Therefore, an inventory of the building would be done to then help plan and design the new building with the soon to be available materials. The building would be constructed simultaneously as the other building would be deconstructed in the same area, therefore, avoiding storing issues, which is a main barrier. Similarly, other results highlighted the need to focus on more local practices to limit the transport of material. Local practices are also favoured because when more stakeholders are involved, the slower the process of innovation diffusion is, as the type of innovation decision is collective with a high degree of stakeholder interconnectedness, according to IDT.

On a broad spectrum, the interviewees highlighted the fast development and use of digital tools in the last 5-10 years. These tools and material banks are developing at different paces with some already being used but still with quite a narrow scope. There is hope for their role in easing the reuse of materials soon, when they are more developed, as the market in itself is not mature yet. They work towards having a broad view of what is available on the

market thanks to data gathering which can document the quality of the materials and thus, increase transparency and decrease risk perception. Therefore, in the framework of IDT, these digital new tools represent many perceived advantages that could accelerate the rate of innovation diffusion.

However, through the lens of IDT, there are challenges associated with digital tools which participate in an increase perceived complexity of developing them. One is the lack of knowledge about digital tools as demonstrated by the fact that most interviewees had never heard of digital tools like BIM and its potential to work with CE. This result is in line with the scarce literature about the potential of digitalization in CE. Therefore, only the participants actively working with CE and in highly innovative environments knew about them. This shows a lack of knowledge diffusion hindering CE since these interviews highlighted the important potential of these tools in facilitating CE. This may be because these tools are still new or used in specific projects. On the other hand, more interviewees knew about material banks, to different extents.

Many projects have been developed since, proving that circular practices in the building sector are possible and further support the observability and trialability characteristic of the IDT. As mentioned before, there is the Circle house in Lisjberj, Denmark, which is designed for disassembly, as 90% of the material will be reusable and is also a certified cradle-to-cradle project. However, an interviewee argued that DFD (Design for Disassembly) is too much highlighted and that for her, the focus should be on the adaptability and repurposing of existing buildings. The example of Varvsstaden in Malmö was discussed as it is the innovative example of a fully-closed loop project as all materials present are reused to construct new buildings on site and the materials are stored in their own physical material bank. Another interview mentioned the Ressource Row, cited in the literature by Langer (2023), which is a building in Copenhagen made out of reused bricks as well as the Rows houses, also situated in Copenhagen, and made out of old concrete panels. Furthermore, an interviewee mentioned the Blique Hotel in Stockholm which was rehabilitated using new digital tools and laser scanning to identify material components.

These examples demonstrated that implementing circular practices in buildings is possible. As certain projects gained recognition in the CE field, they enhance the observability and

trialability attributes following IDT. Indeed, some interviewees explained that the role of innovators and front runners is crucial as they are the ones who embody change majorly and take the risk and try out the innovation first, setting the example. It was mentioned in the interviews that frontrunners can inspire the industry to adopt changes by illustrating successful examples of projects with CE implementation. It could prove to stakeholders and investors that these CE projects are viable solutions. Therefore if more research is done and projects increase their use of digital tools and technologies, it could ease the diffusion of CE practices, leading to lower perceived risks, more investments in CE and accelerate the rate of diffusion according to IDT.

Therefore, the development of new digital tools and technologies has been argued to have a positive impact on the rate at which circular practices are diffused. However, this rate of CE adoption remains low as these tools are slowly getting developed and diffused. These tools were argued to have great potential in mitigating perceived risk as process would be smoother and increase the transparency in the system. It was argued that further development and implementation of new technologies may lead to breakthroughs in the application of CE in the building industry.

Sub-assumption 4: More interconnected networks and knowledge enhance the diffusion of circular innovations in the construction industry and can mitigate risks

Within the framework of IDT's observability and trialability attributes, to increase the rate of innovation diffusion, interviewees talked about the importance of collaboration between companies to extend and spread knowledge. It was exemplified by the Circle houses in Lisberjg, Denmark for example as this project is a collaboration between many companies and architecture studios. This example is also cited in the the literature (GXN, 2018). Similarly, another interviewee explained that a building owned by a Swedish company was going to be demolished but instead, this company gave the building for free to another, which then built an office building in Karlskrona in Sweden with the material. This allowed the traditional company to experiment with circular practices.

In accordance with IDF's perspective on network observability, interviewees cited the example of LFM 30, which was initiated by the town of Malmö. They elaborated that LFM 30 consists of a collaboration among over 200 companies operating in the construction sector, including

material suppliers, consulting firms, academic institutions, constructors, contractors, and others. They are collaborating and working together on different topics and sustainable building strategies to go towards climate neutrality. This cooperation between many stakeholders facilitates the dissemination of knowledge through workshops and initiatives aimed at promoting sustainable practices within the construction industry. Moreover, another interview highlighted strategies for disseminating knowledge within academia and noted the establishment of the new project; *Circular Building Sector* at the faculty of engineering at Lund University, aimed at fostering research in the field. They hosted the discussion panel mixing professionals from the public sector and private sector as previously mentioned in the methodology. Moreover, most interviewees argued that it was crucial to develop more education about CE in companies and universities to pave the way forward. As one interviewee explained, traditional companies are filled with engineers whose main objective is to build safely and follow plans. However, with CE, there is a need to be more open-minded and flexible because materials can change quickly or be non-standardized. Therefore, there is a need for more education and workshops to raise knowledge about CE which is perceived as easy to put in place and therefore in line with IDT's attribute of triability. These examples also align with IDT's emphasis on the significance of communication channels in spreading information about innovation.

The interviews further underscored the many benefits of collaboration, emphasizing that it increases knowledge exchange, thereby facilitating the adoption of methods and processes. The adoption of circular building practices evolves through trial and error, with companies experimenting and learning from their projects. Since these practices are relatively new and lack standardized methods, companies are exploring various approaches. Two interviewees actively involved in such circular projects noted significant positive learning experiences, resulting in faster and cheaper processes. Over time, as practices and technologies become integrated, costs are expected to decrease, aligning with the principles of innovation diffusion. Therefore, collaborating or spreading knowledge can lower upfront costs to other companies since they have a better view of what to do, and the best tools and methods thanks to the trials of innovators and early adopters. Furthermore, one interviewee mentioned that to upscale the use of digital marketplaces, there is a need for more suppliers and buyers to create a network effect and upscale the use of these platforms.

For the perceived complexity attribute of IDT, as of today in most linear industries, collaboration has been highlighted in the interviews to be complicated due to competition that can be detrimental. Therefore interviewees emphasized the need for collaboration between the public and the private sector since CE requires the participation of all stakeholders. One interviewee said that CE was reliant on 80% of the private and 20% on the public sector. Indeed, the interviews argued that the private sector is the primary driver of innovation with new technologies and taking risks for initiating circular projects. Indeed, some interviewees noted that the private sector is already setting higher goals than those set by the public sector, such as lower CO2 thresholds and more ambitious climate impact reductions for buildings. Some argue that this stems from the profit-driven nature of the private sector as focusing on sustainability is perceived as a strong competitive advantage and effective marketing. Thus, they highlighted the importance of the public sector in establishing higher goals and regulations to create a framework for the construction industry to drive change.

Therefore, it has been argued that enhancing network connections and knowledge dissemination can accelerate the diffusion rate of circular practices by mitigating perceived risks, aligning with IDT principles. Currently, despite many efforts, knowledge diffusion and collaborations remain relatively slow but are gradually increasing in Sweden and Denmark.

6.2 End of Discussion Model

Overall, the findings from the literature and the results from the interviews were in line and corresponded which further validated the results found in the literature. Looking at the results, the interviewees all had varying perceptions of complexity of implementing CE in the building industry. Indeed, among the stakeholders and interviews, the risk perceptions were different depending on their level of involvement in working with CE (whether they were working in the field of CE or just in traditional construction industry) and this showed different levels of optimism. The people actively working in circularity were innovators and early adopters so they were optimistic, less risk-adverse and highly engaged in the field to develop solutions which is in line with IDT. Whereas the people working around circularity or not per se in the field, were less aware of innovations and were highlighting more barriers as they knew less about the topic. They were also from more traditional companies and were finding the transition possible but more difficult than the people working with CE.

Therefore, several key points are highlighted regarding the implementation of CE in the building industry. Firstly the need for regulations was greatly emphasised to force change in the highly standardized and traditional sector of the building industry. Financial incentives and funds are needed to mitigate risk since risk perception is the main barrier hindering the development of CE. Therefore, this lack greatly slows down the rate of diffusion and adoption, in line with IDT. Potential solutions, in line with the literature, were talked about such as the development of shared platforms, online material banks and other digital tools to access materials to re-introduce these components in the value chain. There is also a need to develop more networks to collaborate between companies and among the public and private sectors to foster knowledge. This development of knowledge among stakeholders could help spread the innovation faster. Indeed, just like in line with IDT, innovation spreads faster when more people know about it.

While the transition to CE may be perceived as highly challenging, small steps can have a significant impact. Developing CE takes time, trials and failure but it is a part of the learning curve on the development of an innovation. When processes have reached higher maturity, costs are lower and methods are easier to implement and that is in line with further innovation development. Noting the recent surge of interest in the field over the past 5 years, conducted interviews overall express high optimism about the future of CE in the building industry and its potential for further development with the support of simple regulations and incentives. Furthermore, the innovation diffusion progress of CE can be considered currently slow as it is still in the early stage of development according to IDT. Indeed, it corresponds with the beginning of the s-shaped curve and bell-shaped curve showed in Figure 7, which shows that slow progress.

Therefore, with lower risk perception and more transparency over the market, companies can have more incentives to adopt circular practices, even if the proportion is small for now. Thus, small steps can make a big difference in this complex industry. Learning by doing, more regulations and investments can make great changes and help CE to go from just theory to actual practice. This emphasised the need for increased collaboration between the private and public sectors as all stakeholders need to be involved to make this diffusion happen at a faster rate. Therefore, by embracing CE practices and overcoming challenges, the building sector has a great potential to move towards a more sustainable future.

7 Conclusion

As resources are becoming scarcer and demand for housing is increasing, circular economy has been gaining great emphasis recently and is coming up with a solution to change the way resources are used to limit their depletion and reduce waste. The paper aimed to see how could the innovation diffusion theory (IDT) explain the diffusion of circular practices in the building industry. Therefore, this paper only focused on certain characteristics explaining the rate of adoption of circular building practices. Semi-qualitatives interviews were conducted and analysed through the lens of the IDT. It is notable that the answers confirmed the findings in the literature since most answers were similar. The main findings were that the rate of innovation adoption is highly dependent on risk perception.

Therefore, regulations and financial incentives need to be put in place to create a framework for companies and public institutions to shift towards CE in the building sector. Today, the lack of these measures is importantly slowing down the rate of CE diffusion. Furthermore, the findings also highlighted that the private sector is an important driver of innovation as takes risk and has great potential to accelerate the rate of CE practices adoption thanks to new technologies being developed such as material banks and digital tools like BIM. It has been noted that collaboration between companies as well as between the private and public sectors is essential because networks would develop knowledge sharing and collaboration on projects which would minimize risk perception and accelerate the adoption of CE. Moreover, it has been observed that new technologies increase the rate of diffusion but at a slow rate since they are still too little developed as of today. In addition, the results showed that the spread of knowledge through networks has a positive impact on the rate of diffusion of circular practices. Therefore, this paper highlights the pivotal importance for the public and private sectors to collaborate in order to have a roadmap to foster the shift of the industry from a linear to a circular model.

Furthermore, IDT is a theory that aims to explain the overall diffusion process, from innovation to general adoption. However, there are some limitations to this study. Since circular building practices represent a new field, this paper only tried to explain the early diffusion process as it concerns the innovators and early adopters only. This paper dives into the barriers of CE and enablers that could potentially diffuse the innovation further to make the adoption

more generalized. Moreover, the study is context specific to Sweden and Denmark and cannot be generalized to other countries. Furthermore, this study presents bias due to the little sample of interviews and the lack of participants in Denmark. In addition, there is bias on the researcher's side as the study was conduted with pre-existing knowledge and could have therefore ommited other aspects of the topic.

Further research is needed to understand the diffusion of circular practices, perhaps by conducting further interviews with more individuals, particularly those involved in construction law and jurisdictions, which could provide a new perspective to the current findings. Additional interviews could research more real-case studies as they are lacking and explore more in depth the dynamics of supply chains and how to foster interaction among all stakeholders. Additionally, it would be valuable to have quantititve studies exploring the cost-efficiency of circular buildings.

Finally, if circular practices are globally upscaled and implemented, it could revolutionize the use of resources and their processing which would lead to a substantial reduction of harmful impacts on the environment.

8 References

Adam, R. (2019). 'The Greenest Building Is the One That Already Exists', *The Architects' Journal*, Available Online: https://www.architectsjournal.co.uk/news/opinion/the-greenest-building-is-the-one-that-already-exists [Accessed 14 May 2024]

Bocken, N. M. P., De Pauw, I., Bakker, C. & Van Der Grinten, B. (2016). Product Design and Business Model Strategies for a Circular Economy, *Journal of Industrial and Production Engineering*, [e-journal] vol. 33, no. 5, pp.308–320, Available Online: http://www.tandfonline.com/doi/full/10.1080/21681015.2016.1172124 [Accessed 15 May 2024]

Braungart, M., McDonough, W. & Bollinger, A. (2007). Cradle-to-Cradle Design: Creating Healthy Emissions – a Strategy for Eco-Effective Product and System Design, Journal of Cleaner Production, [e-journal] vol. 15, no. 13, pp.1337–1348, Available Online: https://www.sciencedirect.com/science/article/pii/S0959652606002587 [Accessed 21 May 2024]

Bryman, A. (2016). Social Research Methods, 5th ed., Oxford University Press.

Cai, G. & Waldmann, D. (2019). A Material and Component Bank to Facilitate Material Recycling and Component Reuse for a Sustainable Construction: Concept and Preliminary Study, *Clean Technologies and Environmental Policy*, [e-journal] vol. 21, no. 10, pp.2015–2032, Available Online: https://doi.org/10.1007/s10098-019-01758-1 [Accessed 16 May 2024]

Çetin, S., Gruis, V. & Straub, A. (2022). Digitalization for a Circular Economy in the Building Industry: Multiple-Case Study of Dutch Social Housing Organizations, *Resources, Conservation & Recycling Advances*, [e-journal] vol. 15, p.200110, Available Online: https://www.sciencedirect.com/science/article/pii/S2667378922000475 [Accessed 14 May 2024]

Circuit. (n.d). Increasing the Reuse and Recycling of Building Materials [pdf], Available Online https://report.circuit-project.eu/assets/circuit-final-report_chapter2-(1).pdf [Accessed 16 May 2024]

Dearing, J. W. & Cox, J. G. (2018). Diffusion Of Innovations Theory, Principles, And Practice, Health Affairs, [e-journal] vol. 37, no. 2, pp.183–190, Available Online: http://www.healthaffairs.org/doi/10.1377/hlthaff.2017.1104 [Accessed 21 May 2024]

Eberhardt, L. C. M., Birgisdottir, H. & Birkved, M. (2019). Potential of Circular Economy in Sustainable Buildings, *IOP Conference Series: Materials Science and Engineering*, [e-journal] vol. 471, no. 9, p.092051, Available Online: https://dx.doi.org/10.1088/1757-899X/471/9/092051 [Accessed 14 March 2024]

Eberhardt, L. C. M., Birkved, M. & Birgisdottir, H. (2022). Building Design and Construction Strategies for a Circular Economy, *Architectural Engineering and Design Management*, [e-journal] vol. 18, no. 2, pp.93–113, Available Online: https://www.tandfonline.com/doi/full/10.1080/17452007.2020.1781588 [Accessed 15 May 2024]

Ellen Macarthur Foundation. (2022). Realising the Value of the Circular Economy in Real Estate [pdf], Available Online: https://www.ellenmacarthurfoundation.org/articles/realising-the-value-of-the-circular-economy-in-real-estate [Accessed 14 May 2024]

Górecki, J., Núñez-Cacho, P., Corpas-Iglesias, F. A. & Molina, V. (2019). How to Convince Players in Construction Market? Strategies for Effective Implementation of Circular Economy in Construction Sector, *Cogent Engineering*, [e-journal] vol. 6, no. 1, p.1690760, Available Online: https://www.tandfonline.com/doi/full/10.1080/23311916.2019.1690760 [Accessed 14 May 2024]

GXN. (2018). Circle House [pdf], Available Online: https://gxn.3xn.com/wp-content/uploads/sites/4/2019/02/CircleHouse_ENG_2018.pdf [Accessed 16 May 2024]

Hamida, M. B., Remøy, H., Gruis, V. & Jylhä, T. (2023). Circular Building Adaptability in Adaptive Reuse: Multiple Case Studies in the Netherlands, *Journal of Engineering, Design and Technology*, [e-journal], Available Online: https://www.emerald.com/insight/content/doi/10.1108/JEDT-08-2022-0428/full/html [Accessed 21 May 2024]

Hart, J., Adams, K., Giesekam, J., Tingley, D. D. & Pomponi, F. (2019). Barriers and Drivers in a Circular Economy: The Case of the Built Environment, Procedia CIRP, [e-journal] vol. 80, pp.619–624, Available Online: https://www.sciencedirect.com/science/article/pii/S2212827118312940 [Accessed 16 May 2024]

Hjaltadóttir, R. E. & Hild, P. (2021). Circular Economy in the Building Industry European Policy and Local Practices, European Planning Studies, [e-journal] vol. 29, no. 12, pp.2226–2251, Available Online: https://www.tandfonline.com/doi/full/10.1080/09654313.2021.1904838 [Accessed 14 May 2024]

Jelinski, L. W., Graedel, T. E., Laudise, R. A., McCall, D. W. & Patel, C. K. (1992). Industrial Ecology: Concepts and Approaches., Proceedings of the National Academy of Sciences, [e-journal] vol. 89, no. 3, pp.793–797, Available Online: https://pnas.org/doi/full/10.1073/pnas.89.3.793 [Accessed 18 May 2024]

Langer, C. (2023). The Resource Rows, TechnologyIArchitecture + Design, [e-journal] vol. 7, no. 2, pp.175–179, Available Online: https://www.tandfonline.com/doi/full/10.1080/24751448.2023.2245711 [Accessed 14 May 2024]

Nußholz, J. L. K., Rasmussen, F. N., Whalen, K. & Plepys, A. (2020). Material Reuse in Buildings: Implications of a Circular Business Model for Sustainable Value Creation, Journal of Cleaner Production, [e-journal] vol. 245, p.118546, Available Online: https://www.sciencedirect.com/science/article/pii/S095965261933416X [Accessed 20 May 2024]

Owojori, O. M. & Okoro, C. (2022). The Private Sector Role as a Key Supporting Stakeholder towards Circular Economy in the Built Environment: A Scientometric and Content Analysis, *Buildings*, [e- journal] vol. 12, no. 5, p.695, Available Online: https://www.mdpi.com/2075-5309/12/5/695 [Accessed 14 May 2024]

Pomponi, F. & Moncaster, A. (2017). Circular Economy for the Built Environment: A Research Framework, *Journal of Cleaner Production*, [e-journal] vol. 143, pp.710–718, Available Online: https://www.sciencedirect.com/science/article/pii/S0959652616321102 [Accessed 14 May 2024]

Rodrigo-González, A., Grau-Grau, A. & Bel-Oms, I. (2021). Circular Economy and Value Creation: Sustainable Finance with a Real Options Approach, Sustainability, [e-journal] vol. 13, no. 14, p.7973, Available Online: https://www.mdpi.com/2071-1050/13/14/7973 [Accessed 20 May 2024]

Rogers, E. M. (1983). Diffusion of Innovations, 3rd ed. [e-book] New York : London, Free Press, Available Online: https://teddykw2.wordpress.com/wp-content/uploads/2012/07/everett-m-rogers-diffusion-of-innovations.pdf [Accessed 16 May 2024]

Sudarsan, J. S. & Gavali, H. (2024). Application of BIM in Conjunction with Circular Economy Principles for Sustainable Construction, *Environment, Development and Sustainability*, [e-journal] vol. 26, no. 3, pp.7455–7468, Available Online: https://doi.org/10.1007/s10668-023-03015-4 [Accessed 14 May 2024]

Sweco. (2022). Building the Future through Circular Data – Tools for Mining the 'Green Gold' [pdf], Available Online: https://www.sweco.se/wp-content/uploads/sites/3/2022/05/Urban-Insight-by-Sweco_Building-the-future.pdf [Accessed 14 May 2024]

United Nations. (2024). Beyond the Business Case: The Strategic Role of the Private Sector in Transforming the Real Economy [pdf], Available Online: https://desapublications.un.org/file/67/download#:~:text=The%20areas%20in%20which%20the,transportation%20infrastructure%20to%20increase%20energy [Accessed 14 May 2024]

Wonglimpiyarat, J. & Yuberk, N. (2005). In Support of Innovation Management and Roger's Innovation Diffusion Theory, Government Information Quarterly, [e-journal] vol. 22, no. 3, pp.411–422, Available Online: https://www.sciencedirect.com/science/article/pii/S0740624X05000572 [Accessed 16 May 2024]

Appendix A

A1 Question Sample

- Can you explain your role in your company?
- What are the benefits of circular economy in the building industry?
- How do you view your role into making a change towards circular practices?
- What are the main barriers to implement CE practices?
- If implemented, what is the current state of the CE implementation in your company?
- Can you share any examples where these digital tools have been successfully implemented to enhance circularity in building projects? What were the outcomes or benefits observed?
- How do you envision the future evolution of circular practices?
- Is financing difficult to obtain for CE projects?

*The interviews were semi-structured and the questions were adapted to the profile of the interviewees.

Artificial intelligence statement

AI was used to transcribe the interviews with the help of Whisper AI. The interviews were thoroughly checked and listened to again after to ensure the accuracy of the transcription. AI was also used to improve the writing language to a small extent.