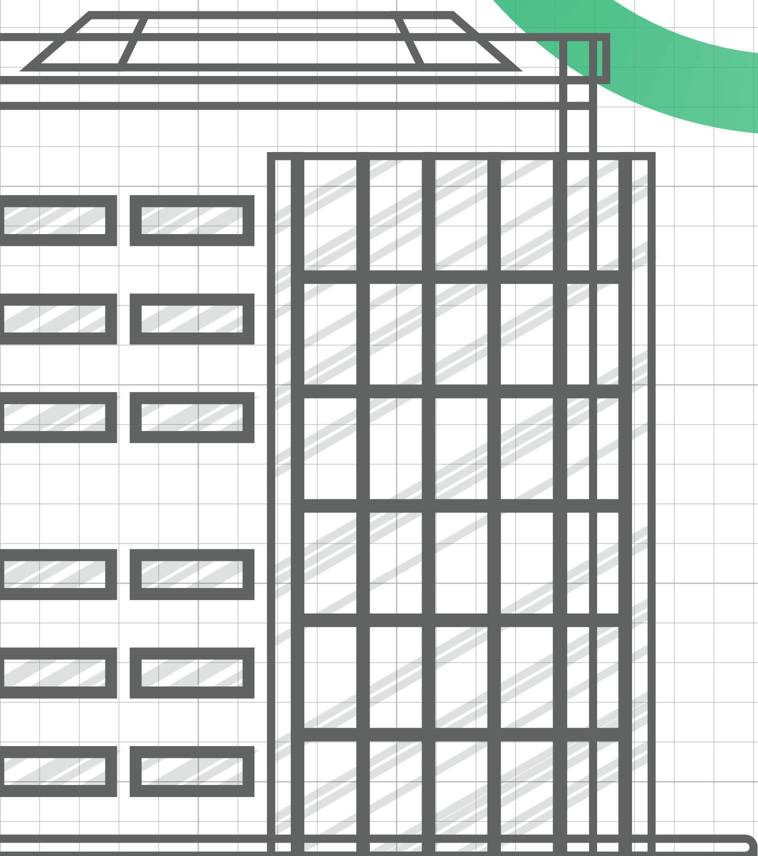
WASTE IS ONLY WASTE IF YOU WASTE IT



A Study on the Requalification of Concrete Waste Materials

- by Frederik Sten Madsen

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ABSTRACT

This thesis' outset is an exploration of the impact of the new EU Taxonomy and what consequences requalifying demolition waste materials would have on the possibility of reaching the thresholds set by the EU Taxonomy. The EU Taxonomy have, among other objectives, set an objective towards enabling the transition to a circular economy. Leading to a problem formulation of:

How does the requalification of demolition waste material affect the possibility of transitioning construction companies towards using 15% reused, 15% recycled, and 20% renewable construction material in accordance with the forthcoming EU Taxonomy?

Seeing as the EU Taxonomy sets requirements for the usage of recycled, reused, and renewable materials used in new construction projects, stakeholders within the industry will be pushed towards adopting practices that can facilitate the usage of said materials. Practices that are not well-established today.

My research and work take outset in a sociotechnical understanding of the world, allowing me to research the linkages between actors, institutions, and technology. In deploying this approach, I have identified discrepancies between how our current linear acceleration economy and circular economy value and know demolition waste materials.

Using the theories in conjunction with a comprehensive literary review, the thesis showcases that reuse of concrete waste materials was the most significant obstacle to aligning with the EU Taxonomy.

Using the theory of Techno Institutional Complexes and lock-in they cause, in conjunction with framing overflow and economisation theories. Enabled the identification of the latent barriers to circular economy principles adoption and used the theory of sociotechnical imaginaries to contextualise the implication of barriers for stakeholders in the construction sector.

The overall result of the thesis concludes that by expanding the requalification of demolition waste materials to encompass the lock-in sources, stakeholders within the industry will be more likely to be successful in adopting circular practices, thereby aligning with the taxonomy.

PREFACE

This thesis is my final project at Sustainable Design Engineering at Aalborg University in Copenhagen. This thesis examines how to better address circular economy issues in the construction sector.

I want to thank Peter Karnøe, my supervisor, who helped me tremendously in navigating a rather large project and problem area. I am thankful for you keeping an open mind in picking out theories and asking the right questions, helping me achieve more.

Furthermore, I want to thank Patrick Moloney from Strategic Sustainability Consulting at Ramboll for making time for long conversations about circularity in the construction sector. Your experienced perspective resulted in many great insights.

And last but not least – Thank you to my lovely family and friends, who have been a great support throughout this project.

Happy reading!

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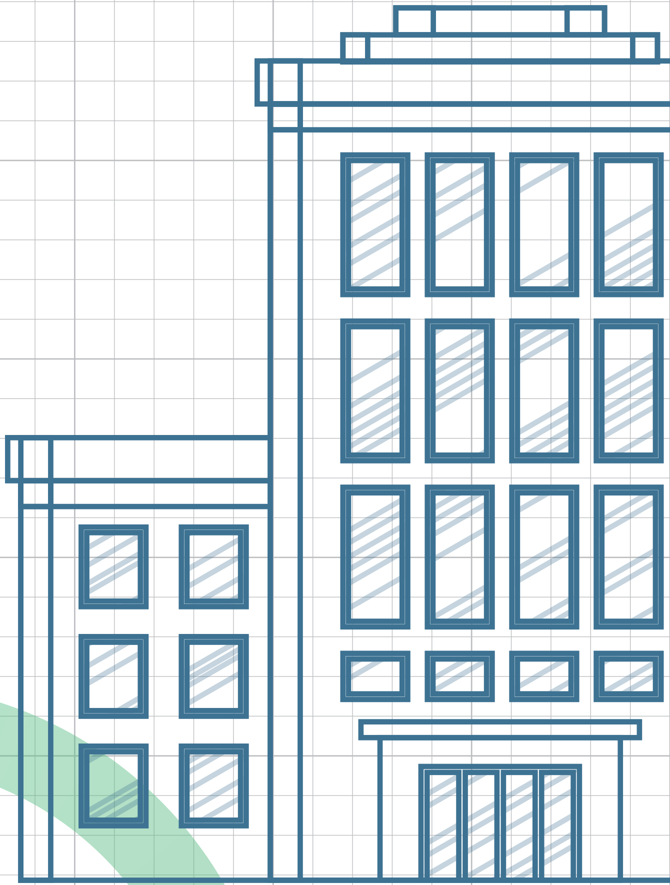
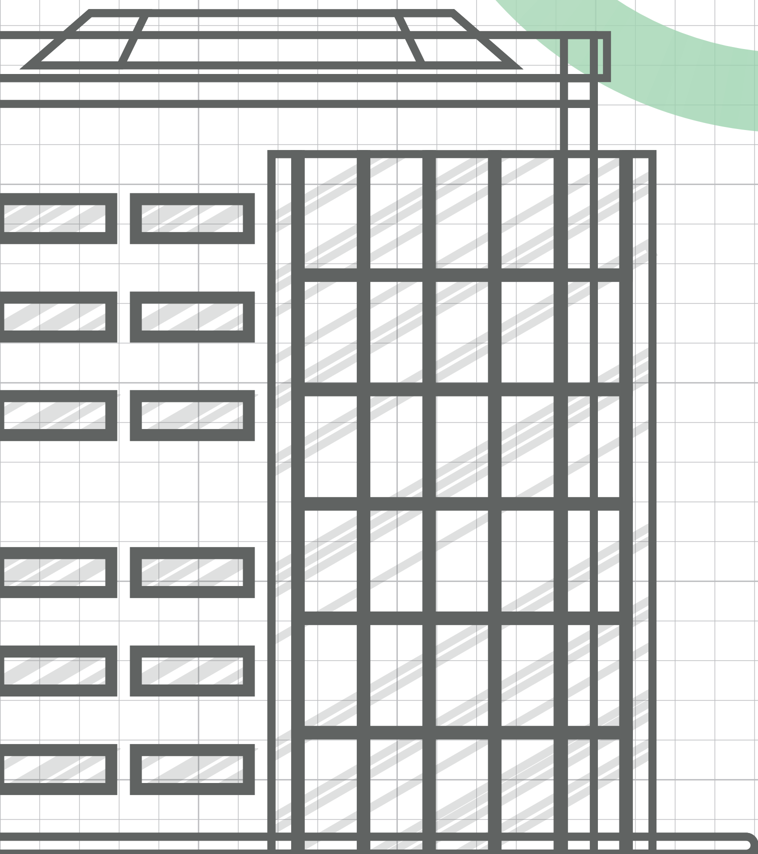


Part 1
Introduction & Overview



1.0 Intro

This year's IPCC report further highlighted the need for urgent climate action, underlining the need to curb rapid climate change. The situation mankind finds itself in is entirely our own doing. Our never-ending hunger for increasing technological and financial riches has taken its toll on our planet. The modern way of life has only been made possible by over-exploiting natural resource stocks, extracting far more than our planet can sustain and replenish, depleting planetary resources. Most of our modern-day goods and services come to be through unsustainable practices. Resources that were once plentiful stand to run dry in the coming decades. These practices are being reinforced and perpetuated through the systems we have built to support them – leaving them in hard to break unsustainable cycles, e.g., society is still reliant on fossil fuel burning energy, even though its contribution to rapid climate change has been known for decades.

This pattern of resource use can be seen described as a linear acceleration economy (Rosa, 2013), where existing forms of economic growth deplete planetary resources. The politics, markets, and culture that enable unsustainable practices are nested within the linear acceleration economy. Unsustainable practices are simply a product of the existing economy, as its inherent nature thwarts any product and system that does not conform to its qualifications. Leading to our major industries being unsustainable by default and design. The existing economy is not punishing unsustainable behaviour. Rather it rewards it in its current form.

For example, our food systems are over-reliant on fertilisers, cold chains, and water while being heavy on greenhouse gas (GHG) emissions. Our transport systems rely on fossil fuels, and our economy promotes unhealthy consumption patterns.

One of the most prominent examples of our existing economy driving unhealthy planetary resource consumption patterns is the building sector. The building sector relies heavily on virgin materials, requiring vast resource extraction to be sustained. Using virgin materials is both energy- and pollution-intensive, having various adverse effects on climate change and eco-systems. The linear economy promotes and rewards the most profitable and cost-effective methods to achieve goals, in this instance, promoting the use of virgin materials.

As this trade-off has been accepted for many years, increasing concerns regarding these externalities have heated the debate on using virgin materials in the building sector. Further amplifying these concerns is that global material use is projected to more than double in the year 2060 (OECD, 2018). With demand for construction materials rising, better resource management and efficiency become crucial to meet demand. As resource extraction continues to drive global greenhouse gas emissions, decoupling the need for construction material from virgin material extraction is essential to curb global greenhouse gas emissions.

1.1 An Alternative to The Linear Economy - A Circular Economy

A prevalent alternative to the extraction and handling of building materials is circular economy. It aims to reduce the use of virgin material as much as possible, instead aiming to reintroduce waste into construction flows as a valuable material. Circular economy aims to view waste materials differently, moving it away from something thrown out over to something reintroduced into the economy as valuable feedstock.

Circular economy is an alternative to the linear acceleration economy, it is fundamentally different in its concept and aim. Proposing normative criteria for partially detaching economic growth from resource extraction. Circular economy does not accept the notion of waste Rather, seeing it is a valuable resource that can be re-introduced into our industries and economy.

At its core, circular economy operates with three different methods to hinder unnecessary material usage: Slowing-, narrowing-, and closing material flows.

- Slowing focus on prolonging the lifetime of a good or material, i.e., designing goods that stay in use for as long as possible
- Narrowing material flows can be achieved by using fewer different materials in goods or less material overall. Alternatively, using less energy for production or production processes is also a form of narrowing
- Closing material flows creates a loop, meaning the material does not become waste and is instead reused in a new process or good

Displacing the current economy with a circular economy will be no easy task. Even though the concept has gained recognition throughout academic and political societies as a feasible alternative to our current economy, circular economy seems challenging to implement in the "real world". The yearly circular economy gap report points toward our economy becoming less circular; developing data-driven tools to enable collaboration, benchmarking, and material tracking are all suggestions to reverse the trend (Circle Economy, 2022). Transitioning towards circular principles and transforming how our economy views waste material will require a significant paradigm shift. The shift will require consumers, industries, and policymakers to change how they operate fundamentally. At the same time, acquiring knowledge that can be equipped to these "new" materials.

1.2 Using a New Economic Sociology to Answer the Problem Formulation

Shifting from a linear acceleration economy to a circular economy requires the consideration of markets and the goods on said markets. This thesis focuses on demolition waste materials and how they can function in a different capacity from what they do now. New social economy will be used to analyse how a shift from a linear acceleration economy to circular economy could look through the requalification of demolition waste materials (Çalişkan & Callon, 2009, 2010; Callon, 1998).

1.3 The EU Taxonomy – A Legislative Pressure to Adopt Circular Economy

Lawmakers worldwide have recognised the potential of circular economy, and several countries and regions have introduced legislation to promote circular economy. One of them is the European Union, with its Green Deal and the accompanying Taxonomy for sustainable activities. The taxonomy quantifies what it means to be circular and allocates responsibility of adoption to several sectors – the construction sector included. It states, among other criteria, that to substantially contribute to the transition towards a circular economy, a new building would have to be built using 15% recycled content, 15% reused components, and 20 % renewable building material or any combination of the three.

I find bringing the taxonomy into play especially interesting for this thesis, as one of the six main objectives is focused on the transition to a circular economy. The taxonomy has put forth tangible performance thresholds outlining what it means to 'actually' contribute to the circular economy. This thesis will, indeed, focus on the aspects presented by the taxonomy, using them to justify and quantify the requalification of demolition waste materials. While setting the success criteria for the adoption of circular economy principles.

A thorough presentation and analysis will be given in sections 4.0 & 4.1.

2.0 Problem Formulation

To successfully analyse the shift required to implement circular economy, this thesis will present new economic sociologies that help frame problematisations while lending an analytical vocabulary to contextualise transitional challenges and complexities.

This thesis sets out to examine ways in which a re-qualification of demolition waste material can occur to frame it as a valuable building material. Using the context of a lack of knowledge and standards on circular economy in the building sector as the outset for my problem formulation:

How does the requalification of demolition waste material affect the possibility of transitioning construction companies towards using 15% reused, 15% recycled, and 20% renewable construction material in accordance with the forthcoming EU Taxonomy?

2.1 Re-Qualifying Materials - Knowing and Valuing Material in The Circular Economy

The existing economy "knows" and values virgin materials in certain ways, favouring them over alternative solutions.

Knowing and valuing a material is achieved through qualification, whereby characteristics and qualities are assigned and agreed upon. Virgin materials have had a qualification that renders them the favoured building material around the World with little to no contention. Leading to the pacification of the usage of materials such as concrete and steel, which have been the dominating building materials for the better part of a century.

In the process of qualifying virgin material, the economy excludes multiple metrics "hidden" in the extraction and use of these materials – and in the process rendering these "hidden" metrics "unknowable" for actors using virgin materials. Hidden metrics could be, e.g., contributing to climate change, planetary resource depletion, and deforestation. It could be argued that these consequences are known and accounted for in the qualification, expressed through the calculation of externalities from material use. However, even though these externalities are known, they fail to influence the attachment to virgin materials, pointing to how virgin materials are qualified withstanding contention from the pressure of negative externalities. To summarise, using virgin materials is so beneficial from an economic perspective that we are willing to live with the consequences.

Re-qualifying materials based on the principles behind circular economy requires that its qualification is not contested. Circular economy is a relatively new concept, meaning that the attempts to qualify waste materials are still hot. Consensus building is challenging, as many different agendas and actors have to agree and assign new qualities to a material formerly framed as something else entirely. Further complicating matters is that data on material availability in already built buildings are not freely available. How does the process of cooling and pacifying goods start when the amounts of material and its availability might be highly contestable?

Stakeholders will have a hard time attaching to materials that they do not find knowable, rendering the framing process unlikely to be successful. Overcoming the formerly mentioned obstacles will require creating new ways of knowing waste materials through standards, calculations and material usage and properties, and in doing so, establishing a frame that can foster the uptake of circular economy principles in the building sector.

As the pressure for sustainable solutions continues to increase, the situation surrounding the use of virgin materials will further heat up, increasing the demand for alternative solutions. Competing alternatives are entering the stage, and work will have to be done to re-qualify new materials for construction work.

In summary, to render waste material knowable in the current economy, it must undergo several re-qualifications while achieving framings that align with distinct stakeholders along the supply chain. Achieving this is no easy task. For it to become a good, knowledge, systems, and value will all have to be reconfigured to enter a new framing.

2.2 Approach and Limits of Scope

This thesis bases its world view on the interconnectedness between people and technology and the formation of linkages between them. Forming complex socio-technological networks of actors, institutions, and technology. The theories chosen for this thesis are mainly based in the sociotechnical sciences, with Hartmut Rosa's theory of Social Acceleration being the exception. I do, however, argue that it aligns well with the idea of sociotechnical networks.

Writing this thesis has been hugely informative, but as I will outline in the coming paragraph, I have had to confine and black-box some of the subject areas of this thesis – both to eliminate unnecessary complexity and keep within the thesis's scope.

As the new EU Taxonomy plays a central role in this thesis, understanding the motives and intended consequences of its implementation is paramount. It is, however, a part of the European Green Deal, which is the overarching plan produced to ensure that the EU transitions to a sustainable society. While being highly important in its own right, it contains various initiatives and legislations not related to the construction industry. Thus, I have confined the inclusion of the European Green Deal to only focusing on the elements relevant to this problem area. Additionally, the EU Taxonomy is quite rigorous in its approach to outline thresholds and criteria for alignment. Hence, I am only focusing on the criteria set for recycled, reused, and renewable building materials. While the other criteria present interesting challenges, including them all would dilute the focus away from demolition waste materials and increase the scope to well beyond the limits set by the expectations of this thesis.

Using Hartmut Rosa's (2013) theory of Social Acceleration allows me to understand why growth is central to society and the economy. Rosa also describes the acceleration of social life and pace of life in his book from 2013, seeing as this thesis' approach and scope are concerned with markets and specific materials. I have limited the usage of his theories to focus on the linear acceleration economy as the subject under study.

Likewise, when considering the construction planning and processes, I have had to limit the subject under investigation in certain areas. I must acknowledge the sheer size and number of stakeholders in a large construction project. This thesis could not possibly allocate enough attention to each aspect without sacrificing nuance and complexity. Thus, I have chosen not to focus on the bureaucratic processes leading up to the start of a construction project – although very influential in the way it shapes construction projects, the assumption is that the building will still be built.

Furthermore, some aspects relating to different recycling and reuse practices will be left black-boxed, e.g., calculating emissions offsets from recycling/reusing construction waste materials. Additionally, I want to emphasise that the thesis will focus on the reuse of concrete waste material. The choice rests on findings that will be further outlined in this thesis. However, the choice can be broadly justified by looking at definite quantities used in the construction sector –the most abundant material used in construction, together with the academic community's recognition of reuse being the least implemented circular strategy.

2.3 Collaboration Partner

This thesis is done in collaboration with Ramboll Strategic Sustainability Consulting (SSC). With which I have had five conversations with during the span of this thesis, mainly focusing on my findings and our mutual interest in the subject area. Seeing as I have been working there as part of an internship, I knew a few 'business secrets' in advance, leading to our discussions being non-disclosable.

SSC is launched to develop a new business consulting department that helps clients create sustainable strategies, comply with sustainability policies, and circular economy. Operationalising circular economy is a relatively new discipline both in general and for SSC, it is a new and unproven activity SSC must learn and experiment with. Understanding how this new area of business can develop. The challenge for SSC is that circular economy is based on new normative criteria for the market, restricting their ability to deploy proven techniques and offerings. Thus, SSC attempts to learn 'on the fly', adding knowledge and experience to their repertoire while they aid clients in solving the very same challenges.

These core services also underline why they wish to understand and operationalise the new EU Taxonomy. The different objectives outlined in the taxonomy align well with SSC's core value offering. The objective "transition to a circular economy" is especially significant for the construction industry.

SSC has identified the technical screening criteria for substantial contribution towards the objective as being quite an ambitious step forward towards circular practices and deviating from prevailing practices in the construction industry. In this way, the unlocking of existing practices is ripe with uncertainties (Unruh, 2002). SSC's client types count both money institutions such as pension funds and entrepreneurs, both clients that would be affected by the taxonomy. SSC strives to be on top of the latest developments on the sustainability agenda, explaining the desire from their side to understand and develop methods to execute taxonomy related deliveries.

My collaboration with SSC makes sense on several levels. I benefit from their experience dealing with long term transitions and sector knowledge, while they benefit from the more in-depth analysis this type of assignment can provide.

The goal of the collaboration is to aid SSC in identifying possible pathways to implementing circular economy at client level. As it is now, they have a broad sense of what circular economy entails. Still, they lack the knowledge to carry out circular economy implementations in sectors that demands special considerations.
Achieving circularity in the construction industry requires separate measures from other sectors. It is not 'just' a case of procuring circular material for production lines. SSC has yet to do any circular economy projects with construction sector clients.

This thesis will provide SSC with a framework to take concrete action in addressing circular economy challenges. By defining which aspects, circular economy is comprised of and supplying them with specific aspects of knowledge on the drivers and barriers for adoption of reuse practices. They get equipped with a tool that can aid them in identifying and quantifying client level challenges.

Furthermore, I will use a design game to explore organisational knowledge related to reuse practices, which can help determine shortcomings in their understanding. The two contributions together will hopefully aid SSC in structuring their knowledge related to circular economy and how to relate that knowledge to the new EU Taxonomy. While giving them the opportunity to develop a service offering grounded in an explorative examination of the problem area.

Their agenda is focused on knowing how the new taxonomy influences the construction sector and how the objectives might be carried out in real life.

Furthermore, they have yet to determine how disrupting the new EU taxonomy will be for industry players. Will it be easily implemented, or will it require significant reconfigurations of industry infrastructures, networks, systems, and practices to achieve alignment? This thesis sets out to examine what the EU taxonomy will entail for industry players and recommend where to focus future efforts.

3.0 Introduction to the Building and Construction Industry

3.1 The Building and Construction Industry

In this section, an overview of the construction industry will be presented while outlining the value chain and key actors along it and the practices that tie them together. Understanding where the construction sector is today is crucial to understanding how it can move towards a more circular future. The construction and building sector are a vast array of different sub-sectors, so to focus my efforts more efficiently, I want to clarify that I'm om focussing on larger building projects. That includes larger residential and commercial buildings that need large structural elements and foundation work.

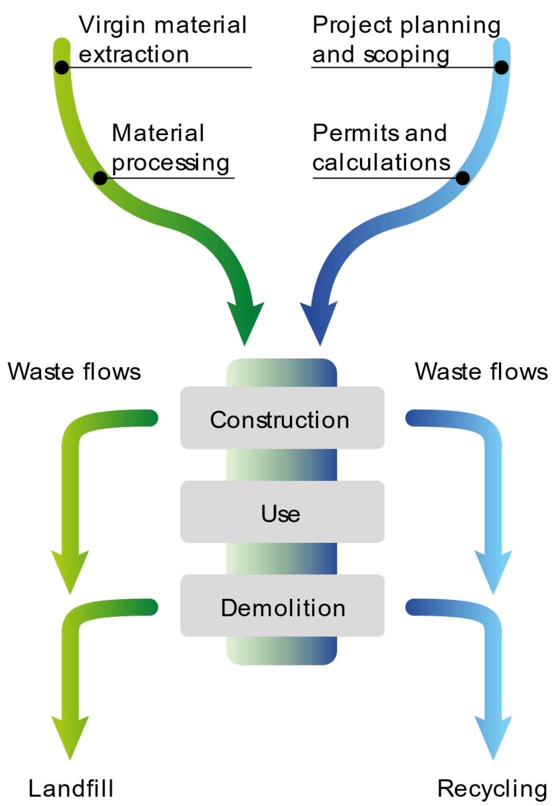


Figure 1: Simplified value chain for construction projects - Own design

The construction sector has an enormous influence around the world. In the European Union alone, 12,700,000 workers are employed in the industry, while investments in the sector accounted for 9.5% of the EU's GDP (*FIEC Statistical Report*, n.d.). However, the 9.5% does not correlate especially well with the sector's resource consumption – accounting for approx. 50% of all extracted material, upwards of 15% of the emissions in the EU and 35% of all waste generation (*Buildings and Construction*, n.d.).

Mankind has constructed buildings on every continent on earth, from the most hostile environments to the most welcoming surroundings we could imagine; humans have built shelter and other buildings to accommodate our every need. While the World's population has increased seven-fold over the last two centuries (World Population Growth - Our World in Data, n.d.), the number of buildings needed to shelter us has followed.

After water, concrete is the most abundant material on planet earth (About Cement & Concrete : GCCA, n.d.), and with populous developing countries building homes for a growing middle class, that will not change any time soon. While maybe disheartening to some degree, it is an immense feat that speaks to the dedication and perseverance of humanity. The enormous infrastructures and systems that must be in place to accomplish such a monumental achievement are hard to fathom. However, you would have to look no further than our modern-day construction industry to find something capable of precisely that.

In the following sections, I will provide an overview of prevailing practices and issues related to the planning, construction, and demolition of buildings.

3.1.1 Material Availability

The prevalent construction practices focus on the use extraction of raw materials from the ground, including raw metal ore mining and ground mineral excavation for foundation and concrete work. The availability and ease of use make raw materials the preferred option. In addition to that, the use of raw materials does not impose any restrictions on the designers; when planning out the building, the only thing limiting architects and designs is costs and the laws of physics, to put it frankly.

To support the building industry's demand for primary materials, primary materials are extracted at an alarming rate (OECD, 2018), which is only projected to go up. The primary materials are then processed at processing plants and manufacturing plants to prepare them for use. The excavation of key metals, ores and materials for concrete is projected to account for 21% of total GHG emissions in 2060 (OECD, 2018). Non-metallic minerals are the most extracted group of materials and include sand, clay, gravel, and stone (Oberle et al., 2019). These materials form the foundation, literally and metaphorically, of our modern-day buildings. The materials are abundant throughout the world and are in no danger of running out any time soon. They are, however, very energy-intensive to work with, couple that with the fact that primary material extraction is somewhat concentrated around a few nations, leading to it having to be transported all over the world – increasing the GHG footprint even more.

Curbing the emissions coming from primary material extraction will considerably improve overall GHG emissions. It will not be easy, as the current structures and practices are not primed to move away from using such materials. Yet, there are solutions that can help bring about meaningful change to the construction material industry. It will be a matter of changing legislation, rallying for better communication between actors, and a change of fundamental assumptions in the building industry. To better understand where these interventions would be effective, the following section will outline the building process from start to finish – albeit a little superficial in terms of detail.

3.1.2 Project development

It is important to acknowledge the complexity of building projects, as multiple stakeholders are involved at different times throughout the project. Thus, this description will present various points of view as different stakeholders have different objectives and roles throughout the process. Additionally, I want to acknowledge that I have chosen to black-box certain elements of the building project, seeing as it does not play a crucial part in understanding the process. Especially aspects of bureaucratic practices and market assessments, seeing as the assumption is that the building will be built. Meaning that factors such as approval from municipalities and economic drivers – commercial, residential etc. will be left black-boxed.

Before the building project can start, several factors need to be considered. First of all, there needs to be a site where the building can stand. Either it will be an empty area, or there will be a building there beforehand. Nevertheless, a developer will own the lot, they will either have to lay out a demolition plan or send out a tender for the design of a new building. These two aspects have implications for the transition to circular economy but seeing as this is a general overview, I will not be going into detail in this section.

The developer will determine a set of requirements and criteria for what they need the building to be from assessing the site attributes. Then formulating said requirements and criteria into a tender. The tender will either be allocated to a predetermined architect firm or sent out as a case competition where multiple firms can submit their proposal to fulfil the tender.

The architects will consider the site attributes, requirements, and criteria. Designing a vision for what the building could be. Again, this part of the process has implications for circular economy adaptation but will remain black-boxed for the time being. After the developer has approved the design, structural engineers start calculating how the building is going to be built and how much material is needed. The developer will initiate talks with contractors who can carry out the task. Depending on the project, a single contractor can carry out the whole project, although it is more common that multiple contractors are hired to carry out the project. Each contractor will procure the amounts they need to fulfil the part they have been hired to do. Leading to a poor overview of the total amounts used, which raises implications for circular economy.

3.1.3 Construction of the Building

As the construction teams begin to populate the construction site and the building starts to take shape, waste accumulates. Waste generated during the construction of the building comes primarily from construction material packaging and damaged materials. The materials used are mainly comprised of concrete; although other materials such as rebar and gravel are also used, close to 90% of the weight of the building is made up of concrete (Birgisdóttir & Madsen, 2017).

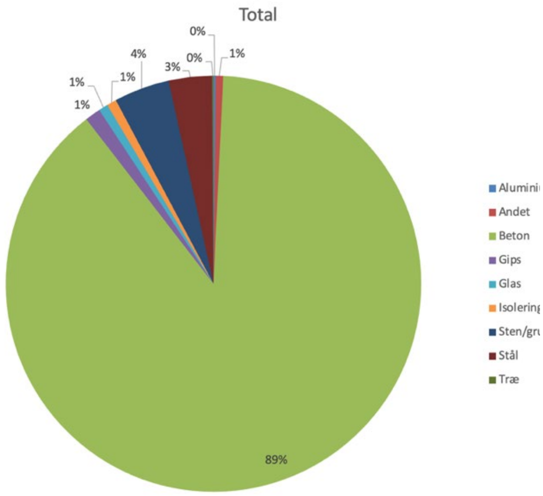


Figure 2: Material composition of a 12.900 m2 office building, data analysed and collated by me – See Appendix for the data (Birgisdóttir & Madsen, 2017)

Both data and observations support the fact that concrete is the favoured building material of choice, and indeed looking at life-cycle data confirms the assumption. Concrete in construction projects is used in two different ways, cast on-site concrete elements (in-situ concrete) and pre-cast concrete elements (*Precast Concrete vs Site Cast Concrete | Nitterhouse*, n.d.). The in-situ concrete benefits from not adhering to transport restrictions and can be customised to specific conditions. While the pre-cast concrete benefits from ease of use and economics of scale. The aforementioned office building is mainly comprised of pre-cast sandwich elements. Pre-cast elements have the potential to fit into design for disassembly practices but do not at the time being.

The data confirms that action needs to be focused on concrete since most of the waste generated from demolishing a building will be concrete waste. Recycling concrete is a well-established practice, although questions pertain to the value of recycling. In contrast, reuse practices are poorly implemented, as has been established by the literary review.

3.1.4 Current Demolition Practices

Due to a rather convenient coincidence, I have had the chance to observe an ongoing demolition. Seeing as the neighbouring to me is being torn down, I have had the opportunity to see the day-to-day steps of tearing the building down. I consider the demolition job in question representative for demolition jobs in general. Reasons for this being (i) The building is of no special status, just an ordinary building. (ii) It is not part of any *prestige/spearhead* project (iii) It is built from mainly concrete, which most buildings are. I find the demolition project to be generally in line with ordinary practices, with no special treatment or considerations going into the task.

The building is a large commercial building with a warehouse/workshop layout and relatively simple with no complicated structures or interiors. Consisting of a structural concrete frame and concrete walls with Rockwool isolation, with timber rafters as support for a flat roof – probably asphalt roofing.

Picture 1: (*7 Rebslagervej – Google Maps*, n.d.)

Picture 1 shows the building as being relatively simple in layout and construction; following the demolition work, I was able to see that the inside structure was straightforward too. The structural concrete frame acted as room dividers, making the room layout very simple. From someone interested in the adoption of circular economy, seeing a perfectly good building getting torn to shreds seems a bit unnecessary from my point of view – see Picture 2. Without the precise details of this building's construction methods and components, it is difficult to assess if it could have been done in a better way. It is possible, at least plausible, that it could have been demolished to accommodate circular principles better.

Picture 2: Own photograph / 6th. of May 2022 - Building nearly torn to shreds

Before the building ended up in the state, which can be seen in Picture 2, I observed that windows and appliances were removed from the building, which could point to a more specific recycling scheme that tries to salvage higher value materials. In terms of the concrete elements, they were destroyed to a point where the only option was to entirely separate the materials, even though, as Picture 3 shows, some of the elements could potentially have been salvaged in an undamaged condition. Seeing as the element is nearly whole, one could imagine that it would not have taken much more effort to salvage it whole. As can be seen in Picture 4, it does, however raise some complications, as the elements were comprised of several different materials, such as rebar, Rockwool isolation, and flamingo isolation. I can only speak of the outer walls, as they were the only ones I had access to. Thus the internal structural components could be made up of only reinforced steel.

Picture 3: Own photograph / 6th. of May 2022

Picture 4: Own Photograph / 2nd. of May 2022

In summary, the construction sector plays an immense role in our resource use and waste generation. Furthermore, multiple stakeholders are involved in the construction process at any given time, leading to complicated procedures and a non-transparent supply chain. Which causes poor overview of material use in the construction phase.

Additionally, the prevailing construction practice being concentrated on concrete leads to large amounts of concrete waste that need either recycling or reuse to align with circular principles. However, as can be seen from the review of general demolition practices, there seems to be a lack of consideration for future reuse of building components. Aspects that will be handled further in the literary review and analysis.

4.0 The EU Taxonomy for Sustainable Activities

The EU Taxonomy for sustainable activities is a classification system, made to establish a list of environmentally sustainable economic activities. Being a tool of the European Green Deal aimed at combatting greenwashing (*EU Taxonomy for Sustainable Activities | European Commission*, n.d.). The EU has developed the taxonomy with the aim of increasing investments towards sustainable activities, in doing so aiding in achieving the goals set forth by the European green deal. The intent is to provide investors, companies, and policymakers with suitable definitions of which economic activities are environmentally sustainable (*EU Taxonomy for Sustainable Activities | European Commission*, n.d.).

The taxonomy uses the NACE code system to appoint which economic activities are affected by the taxonomy. The NACE code system is a European broad statistical classification of economic activities – e.g., a NACE code classification: F41.2 - Construction of residential and non-residential buildings (*EUROPA - Competition - List of NACE Codes*, n.d.).

The EU has defined six environmental objectives:

1. Climate change mitigation
2. Climate change adaptation
3. Sustainable use and protection of water & marine resources
4. Transition to a circular economy
5. Pollution prevention and control
6. Protection and restoration of biodiversity and ecosystems

For each of those six objectives, a list of eligible economic activities is listed that may substantially contribute toward that specific environmental objective. An economic activity can be seen as substantially contributing if it complies with the technical screening criteria listed for each objective. The delegated acts specify the technical screening criteria, which also specify which economic activities are eligible for screening and which performance threshold needs to be met.

Complying with the EU taxonomy then becomes a matter of complying with specific technical screening criteria for a given economic activity. The technical screening criteria are comprised of a section that outlines how an economic activity can substantially contribute towards a given objective, then it presents the "*Do-no-significant-harm*" criteria for the rest of the objectives. Lastly, the activity would have to meet the minimum social safeguards.

Seeing as the European green deal is set to follow the Paris agreement, the taxonomy will evolve dynamically with the goals. Making the performance thresholds progressively harsher thus, it is anticipated that the taxonomy will change often. Meaning that a company could be aligned one year but would not meet the technical screening criteria the next. Some financial activities are listed under more than one of the six main objectives. In those cases, the company carrying out the activity can choose which technical screening criteria for substantial contribution they will adhere to. However, they still need to meet the *do-no-significant-harm* criteria, arguably handing the *do-no-significant-harm* criteria deciding power over the substantial contribution criteria. This observation is essential, in part because some of the substantial contribution criteria can be seen as implausible to comply with, leading to companies that can choose to pick the less difficult option. In part because some of the other substantial contribution criteria are relatively easy to comply with, meaning they are close to business-as-usual practices. Having the *do-no-significant-harm* enforces that some elements are unavoidable to comply with.

4.1 The Technical Screening Criteria for Substantially Contributing Toward the Transition to a Circular Economy

This section has (PLATFORM ON SUSTAINABLE FINANCE: TECHNICAL WORKING GROUP, 2022) *as a source. However, I will deviate from my typical formatting of references due to the extraordinary length of the source in an attempt to aid readability.*

The construction of new buildings and major renovations has been deemed an economic activity that can substantially contribute toward the transition to a circular economy. To be more specific, the NACE codes listed are:

- F41 - Construction of buildings
- F41.1 - Development of building projects
- F41.2 - Construction of residential and non-residential buildings
- F43 - Specialised construction activities

(*EUROPA - Competition - List of NACE Codes*, n.d.)

From the NACE codes, it is clear that the technical screening criteria will affect a broad array of activities, which will undoubtedly result in implications throughout the different phases of construction projects, even though the NACE codes are somewhat ambiguous in the way they describe activities. It should still be clear that most, if not all, construction projects fall under the categorisation. Furthermore, project planners are also affected, seeing as the development of building projects will have to comply. The inclusion of developers in the technical screening criteria means that building designers would have to factor in the criteria in order to comply. Thus, putting pressure on architects to shift their practices to accommodate circular practices.

I will not be going through every single technical screening criterion for substantial contribution toward the transition to a circular economy, as it will be outside of the scope of this thesis. Examples are criteria for construction waste sorting (packaging waste and residuals) and asbestos usage. Yet, several criteria present an attempt to inhibit current practices and push for more circular practices.

A Life Cycle Assessment (LCA of the entire project will have to be calculated through all the building's life cycle phases and made available for disclosure to clients and investors. Architects and project planners would have to incorporate design for adaptability and disassembly principles into their designs – This should encourage greater reuse and recycling. Developers would have to use Building Information Modelling (BIM) or similar software to digitally map the whole building to aid decision making and easier dismantling. While securing that information of the material make-up of the building stays up-to-date and available. All these performance criteria are relatively easy to accomplish, apart from the design for disassembly criteria. It will require a shift in practices but is deemed attainable.

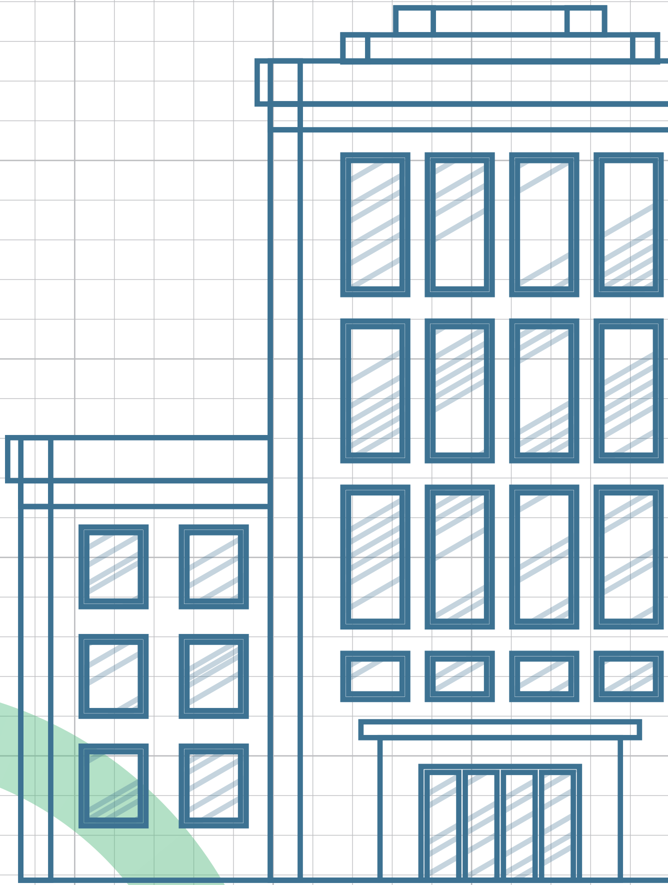
The biggest obstacle to achieving compliance with the technical screening criteria is the demand set for reusable, recycled, and renewable materials used in the new building. The thresholds are not yet set in stone, but any demands placed will disrupt the construction sector. The literary review will outline more detailed reasons for this, but it seems clear that it will be a monumental shift from prevailing construction practices. The criteria will be comprised of certain percentage thresholds needed to be upheld – determined by the weight/surface area of the building.

Recycling is the most common form of material recovery, but it is not a widespread practice – only accounting for a few percentages of total weight, if any. Component reuse is virtually non-existent in the construction sector.

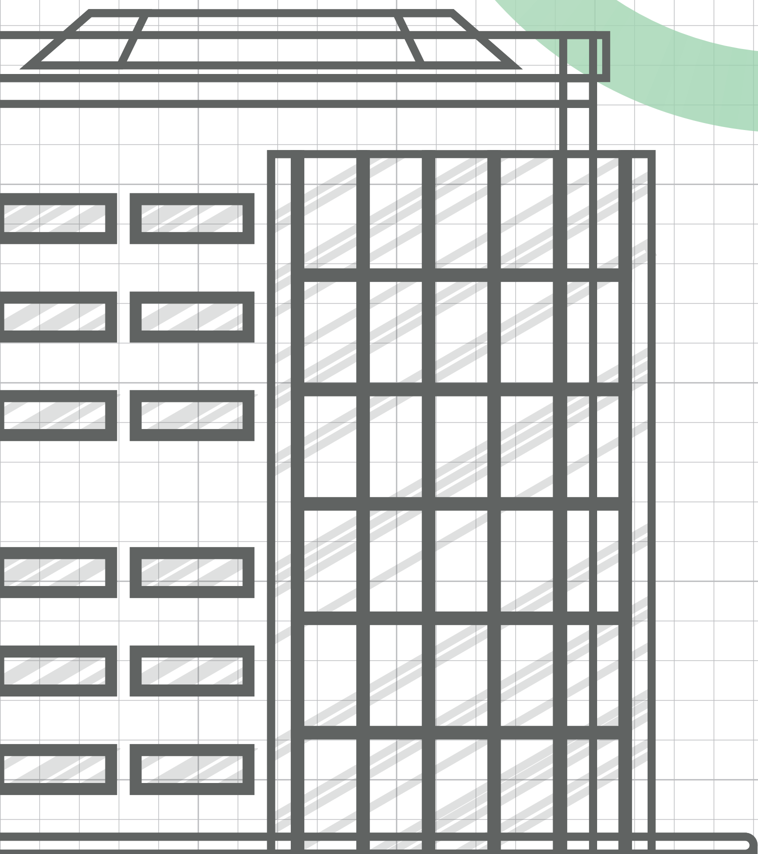
If compliance is to be accomplished, the criteria will set in motion a shift in demolition practices to harvest reusable components. Lastly, the criteria will push developers towards a higher degree of timber usage, although bio-based isolation could also be an option.

As it stands now, the thresholds are to be set at 15% recycled content, 15% reused content, and 20% renewable content or any combination of the three types of material. Project developers would have to source 50% of the building materials from suppliers that operate with respect to circular principles.

The *do no significant harm* section is, of course also important, but they do not revolve around circular principles. Hence, they will not be described in this section. However, it is important to acknowledge that it seems probable that weight/surface area thresholds will be included in the *do no significant harm* section of the other five objectives. Although not as ambitious as the substantial contribution thresholds, it will still force construction companies to source material from circular sources if they wish to comply.



Part 2
Theory & Methods



5.0 Theory and Method

In the following section, I will present the theories that I use to contextualise the problem area. Theories are tools for thinking about specific circumstances. Thus the theories chosen lend me a particular vocabulary to describe situations from a certain point of view and give me tools to situate complex real-world problematisations in a framework that can render them analysable. Theories let me create the world boundaries that I wish to analyse, aiding in making structured representations of the real world. Thus, giving me tools to look at the endlessly complex and chaotic world without unnecessary static noise – it paints a clearer and more comprehensible picture. Choosing theories is a painstaking process seeing as a theory is applied, it reduces complexity in terms of particular and situated nuances. Contrarily, it amplifies standardisation, circulation and compatibility of the knowledge produced, alleviating some challenges in uniting different theories (Casper & Latour, 2006). Thus, one needs to consider what elements are part of a theory, but just as much being aware of what is left out.

5.1 Data gathering in Relation to Ramboll

I have gathered knowledge concerning Ramboll through the interviews I have conducted with them. However, both the fact that I was not allowed to record our meetings and the conversational nature of the interviews means that I had to rely on the notes taken during the interview. However, as I worked in the department for six months, I have a certain amount of personal experience to back up the observations from the interviews.

5.2 Our Current Economy is Unsustainable

Today's economy is largely responsible for the challenges we face in terms of climate change and depletion of planetary resources. The World economy is built on the principles of capitalism, making it a capitalist economic system. It is centred around the idea of a free market where market participants are free to decide who and how they want to participate. Without getting into specifics of the current economy, certain economic structures help to enable unsustainable practices. The way we consume is characterised by what scholars tend to call a 'take-make-dispose' economy (Benachio et al., 2020; Eberhardt et al., 2019). Combining the 'take-make-dispose' tendencies with the capitalistic wish for perpetual growth thus creates a loop of ever-increasing demand for resources and materials to satisfy demand. Again market drivers and mechanisms have been severely black-boxed in this description, but it aims to highlight how our economy is driving both emissions and depletion of planetary resources. In the following sections, I will contextualise the claims made in this section by introducing theories which lend credibility to the claims made.

I want to first introduce the theory of Social Acceleration to contextualise the claims made about the economy. Adding the Multi-Level Perspective to describe how technology evolves in said economy. However, both are not well equipped to address the actors and institutions situated in the market. Thus I want to introduce the theories of framing and overflow together with the idea of economisation to understand the actions of said actors. The materials that actors engage with will be put in a broader perspective by calling upon the theory of lock-in. Lastly, sociotechnical imaginaries will be introduced to understand the visions of a better future projected by the aforementioned institutions.

5.3 Social Acceleration - Hartmut Rosa

The "Social Acceleration" theory by Hartmut Rosa (2013) is suitable to help think about and understand how Western societies or industrial societies got to a situation where our way of living is unsustainable. A form of living that seemingly is very difficult to change, requiring strong political will to enact positive change. Even with initiatives such as the transition to green energy, Rosa (2013) argues that there are underlying societal structures that dictate our pace of life. Leading to a society that perpetually seeks to expand and accelerate, increasing our demand for planetary resources to keep up. This could help to explain why progress seems slow and reactionary in nature, the social structures might inhibit radical change if not considered.

Social Acceleration attempts to explain why our society develops at the pace it does and which factors play an essential role in upholding these structures (Rosa, 2013). Rosa (2013) argues that acceleration is happening within three central aspects of society – technological acceleration, acceleration of social change, and acceleration of the pace of life (Rosa, 2013). Especially the acceleration of technology is relevant to explaining why the depletion of planetary resources continues to rise. As Rosa states:

> *"In the capitalist economic system, however, the continually rising speed of production necessarily goes hand in hand with the escalation of speeds in distribution and consumption, which are in turn driven by technological innovations and thus share responsibility for the fact that the material structures of modern society are reproduced and altered in ever shorter periods of time."* (Rosa, 2013, p. 74)

Hence, the book gives an approach to understanding the construction sector as part of a larger historical regime of growth and development. The societal structures that enable and preserve the unsustainable practices that our current system favours need to be understood to intervene and enact positive change. Hartmut Rosa's theory on social acceleration can help explain how the structures around us seem to combat interventions such as circular economy.

However, the theory of social acceleration lacks the level of detail to reflect upon these structures thoroughly. Seeing as Rosa 'only' divides the social structures into the three aspects of social acceleration. While definitely helpful in understanding the underlying factors enabling over-consumption, it fails to adequately explain sociotechnical transitions, which is why I have elected to include both Geels (2002) and Unruh (2002) in the analysis.

5.3.1 Social acceleration in the construction industry

A society that seeks to be constantly accelerating, be it technology, social change, or pace of life, can be hard to keep up with. Hartmut Rosa focuses on how the structures of society enable the exploitation of planetary boundaries, as his theory seeks to explain the dynamics of the linear acceleration economy. This acceleration results in acceleration in the use of primary resources, thus fuelling the depletion of resources as there are no checks in place to replenish extracted resources. Making it a linear acceleration economy which is diametrically different from the principles of circular economy.

Hartmut Rosa points out that, as society strives to develop new and better technologies, it accelerates the need for materials and processes that can facilitate the latest technologies. It creates a double-edged sword, as both the technology and the infrastructure to support it needs increasing amounts of resources to keep going. The consequence is that our ability to consume resources increases as long as we keep accelerating.

The acceleration of social life and pace of life plays a role in upholding the structures that facilitate technological acceleration. Yet, for the sake of this thesis, the scope will be limited to looking at how the accelerating society's need for increasing material and economic resources sets demands for regulators to keep the acceleration going. Rosa's worldview lends the opportunity to recognise and understand the dynamics of our economy from a certain point of view. Rosa's theory attempts to contextualise the seemingly neverending cycle of growth and expansion that we experience while also explaining why the cycle is so hard to break. As he states that it is the default configuration of our society, permeated throughout our political and technological agendas (Rosa, 2013). His worldview makes it possible to articulate the latent barriers to new ways of organising society, as it puts focus on the mechanisms that perpetuate and reinforces existing structures.

In Hartmut Rosa's book, his criticism lies partly on the capitalistic economic system that he claims ensures that productivity and efficiency continue rising. As he states:

> *"(…)then in the first place labor time directly constitutes a decisive, i.e., value-creating, factor of production, as time is transformed by work into value. Insofar as the exchange value of a commodity is determined by the (socially necessary) labor time embodied in it, the economization of production time can be immediately translated into (relative) profit"* (Rosa, 2013, p. 162)

Thus, going by this perspective, it is in an economic sense logically favourable to ensure that labour can work as effectively as possible, i.e., it secures a competitive advantage. However, increasing efficiency requires, in many instances, new production methods, meaning new and better machines, bigger production facilities etc. As competitors seek to catch up, they too will invest in better equipment until they close the gap and equilibrium is reached. The cycle can then start over as market participants seek to gain competitive advantages over one another.
The example above is only one instance of the capitalist economic system working to increase its profits and in doing so, increasing its consumption of planetary resources. If we accept the premise set by Rosa (2013), then it is not farfetched to claim that the current capitalist economic system favours growth and, by proxy, resource consumption.

Thus, when thinking of how the idea of circular economy challenges the very core of the capitalist economic system, it is important to acknowledge that the changes that need to happen are not only superficial, the principles of the new circular economy are in direct opposition to the efficiency principles that Rosa finds fundamental for economic structures.

The philosophy of circular economy tries to align, to some extent, with these structures by promising the possibility of economic growth detached from resource consumption. The EU describes it as *sustainable* growth, but how detached that is, remains to be seen (*Circular Economy Action Plan*, n.d.). Thus, pandering to the capitalist economic system that, as we have established, favours growth.

Despite it being an important way of thinking about our societal lock-in, the theory presented explains the linear acceleration economy from the perspective of a passive onlooker, acting more as a cause-and-effect description, i.e., to treat a sickness, you must first identify the symptoms and diagnose the disease. Hartmut Rosa's description of social acceleration is a valuable entry point to understanding why it is we consume resources at the rate that we do. But it has little guidance on the actors involved in a transition process and how agency can be distributed between stakeholders to enable a transition.

5.4 Multi-Level-Perspective (MLP) – Geels

Rosa describes *why* technical innovations happen at the pace they do, describing the societal structures that cultivate innovation – To uphold the social acceleration, efficiency in production systems needs to keep increasing, which, as demonstrated eventually leads to innovation. It fails to explain the structures that enable *how* they come to be and through which mechanisms that allow for such technical transitions.

Geels' multi-level perspective theory offers a way of thinking about and examining technical transitions through different magnitudes of sociotechnical networks (Geels, 2002). The transition of the current linear-economy construction sector towards a construction sector based on the principles of circular economy undoubtedly contains a technical aspect. According to Geels (2002), sociotechnical transitions cannot be reduced to only the technical component. The main argument of MLP is that for sociotechnical transitions to be successful, several different functions and levels of sociotechnical networks need to be investigated – hence the name.

This multi-level perspective makes it a compelling theory to employ in analysing the problem area. He presents the view that technical transitions unfold in three intertwined levels: The landscape-, regime-, and niche level (Geels, 2002). The levels describe the trends that drive technology and at which pace those trends change and can be influenced. The landscape is a macro-level view of our world, consisting of the fabric that sets the trajectory for governments, technology, and culture.

While the regime describes the meso-level, which sets the rules and trajectory for actors in sociotechnical groups seeking to drive change.

The niche level is the technological trajectories viewed at a micro-level. It is here that radical change can happen because there are no ingrained structures to cohere to, no bigger sociotechnical groups to fit into. It is a place where you can experiment and make mistakes. Changes happen when "windows of opportunity" appear. They happen when disruptions to landscape, regime and niches happen, allowing for niches to break through (Geels, 2002). Geels explain why changes happen and how to cease the windows of opportunity to create changes to the other two levels. Especially with the introduction of strategic niche management (Schot & Geels, 2008). However, strategic niche management is still not suitable for examining how to transition toward a circular economy.

Several factors play into this observation, as it could both be argued that the work related to circular economy cannot be classified as niche work and that circular economy is not a new technology. Instead it is a new way of organising already existing technology, knowledge, and regulations to fit the principles of circular economy. Simultaneously, the transition is, in its essence, a transition of financial markets and how they view material. The technologies to adopt circular economy is present, but the market for those technologies to be a viable option for market participants is not. Market participants need to reconfigure how they view and know waste materials, to allow the materials to circulate on the market.

Geels' multi-level perspective theory is a great framework for thinking about technological regimes and how they change. However, as can be seen in his model of the multi-level perspective:

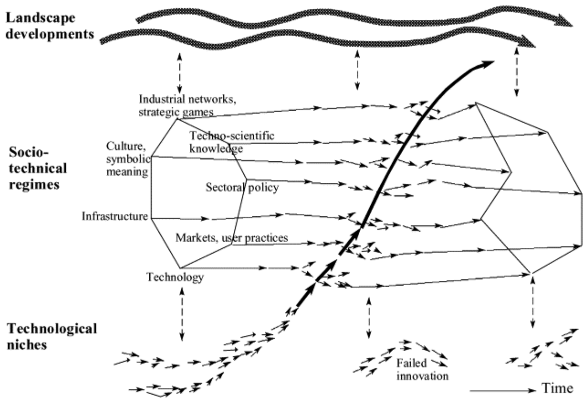


Figure 3: (Geels, 2002, p. 1263) The multi-level perspective from Geels. The shows the general overview of how the three levels relate to each other. While also illustrating how technical niches break through to the regime and landscape levels.

It does not offer much explanation of what the Sociotechnical regimes consist of, such as markets, infrastructure, and technology. They remain black-boxed as just a part of the fabric of reality, failing to acknowledge action from within these regimes. Thus, the MLP theory does not offer the ability to think about the intricacies of markets and infrastructure from the inside, which are two core elements of this thesis. Showcasing the need for further theories that can help think about and analyse markets and how they develop.

5.5 Markets Understood as Constructed: Actors and Framing Overflow

I have chosen Callon's theory on framing and overflowing as a way to open the formerly mentioned black-boxes (Callon, 1998). Seeing as the theory offers an insider's perspective that emphasizes following actors engaged in market activities. Furthermore, it lends the opportunity to look at their concerns and their attempts to reconfigure market worlds. New market arrangements that focus on being less aligned with the current linear capitalist economy, instead aiming for a more circular economy.

As formerly stated, the lack of market options for circular materials hinders the adoption of circular economy principles. To make demolition waste materials a viable alternative to primary sourced construction materials, they need to be re-qualified - bringing their latent/tacit qualities into play.

Callon's theories on framing and overflows underline the importance of understanding how market participants know and understand goods. Certain goods have certain framings that allow them to function on the market. However, it is the very framing that determines the good's value and function. If the framing changes, then so does the application of the good. A good is only viewed in a particular capacity because market actors have decided on the specific framing. Framing a good both determines what a good is and what it is not. Thus, framing a good present a natural tension between what to keep in the frame and what to leave out.

Framing and overflowing can be used to understand how Rosa's linear acceleration society creates a specific framing of goods. A framing that favours primary and readily available materials in isolation works to enable the business models of the linear acceleration economy. Yet, this framing generates an overflow in the resulting depletion of planetary resources. Circular economy is a specific response to re-frame the market framing of goods for construction, aiming to include waste materials in the frame. Allowing it to circulate in a different capacity than the old framing.

This way of opening the black box, i.e., understanding how certain goods are qualified, known, and valued by the market, becomes a possible way to address inadequacies and failures created by the current market structures. The process of qualification allows goods to be known by the market; the market knowing a good then enable it to be pacified. Only then can the good be framed, as market participants now know the qualities of the good.

Looking at construction and demolition waste materials, it is clear that for them to circulate differently from what they do now, they need to be known in another way than what is the case now. Using the biomass case by Karnøe et al. (2019) to draw similarities between the two goods, I will try to outline how the framing of goods influences its function on the market.

Biomass has been a contested area for policymakers and climate advocates for decades, leading to several different framings of the material. New ways of carbon emission counting led to the material being contested; critics was starting to point out that burning biomass could not be seen as only carbon neutral, as several factors influence the circumstances for carbon neutrality. The dispute led to the situation surrounding biomass to heat up. As result the qualifications of biomass as a carbon-neutral material became contested, and new concerns could enter the discussion.

The key takeaway from the biomass case is the acknowledgement of all the "hidden" processes that go into the positioning of a good on the market. A good does not start circulating differently if work has not been put in that makes it such. Karnoe et al. (2019) point to the governance systems that render goods knowable, such as standards, classifications, legislation, and regulations. These factors then are what lock in use patterns of said good. When a good becomes known, it is possible to plan with it in mind, and thus the good anchors itself into structures of use that can be difficult to change. Suppose we view construction and demolition waste materials in a similar capacity to biomass, meaning a good that has considerable knowledge assemblages behind it. In that case, a substantial amount of work will have to go into re-qualifying construction and demolition waste materials.

This tension is quite interesting to analyse, as it shines a light on which actors work to keep a certain framing and which actors work to establish a new frame. Furthermore, contrary to both Hartmut Rosa and Geels' theories on the social world, it gives opportunity to delve straight into the engine bay of market creation and dynamics. Lending a more dynamic view to analysing the transition toward circular economy. As formerly mentioned, Rosa outlines why society seems to be stuck in unsustainable practices, while Geels outlines how technical transitions come to be. Yet, the transition to circular economy cannot only be viewed as a technical transition. Aspects of re-qualifying goods must be included in the analysis to fully grasp the complexity of integrating circular economy into the construction industry. The theory allows me to situate the analysis in the middle of the change rather than be a passive onlooker who describes change after the fact.

5.6 Re-Inventing the Economy in The Construction Sector - Çalişkan & Callon

For circular economy to be thriving, the economy would have to view construction and demolition waste materials in a different capacity. Callon's theory on economisation is used to think about what criteria need to be present to achieve the economisation of construction and demolition waste materials.

Çalişkan and Callon (2010) describe three key agents in the economisation process (Çalişkan & Callon, 2010, p. 2). The first key agent is economic theories used to understand and intervene in the economy. Shifting from a linear economic growth process to a circular economy to reduce the use of resources and reduce waste materials would require a re-framing of the market for the goods in question. A reframing would allow goods to be valuable on different criteria for being 'valuable goods' instead of what they are today – that means that waste must shift from being of little use to being of major value. Thus, as a normative guide for re-designing the principle for the economy, circular economy has the potential to drive a reframing of existing markets that can facilitate the conception, production, and circulation of waste materials. As Çalişkan & Callon (2009) state:

> *"The forces that explain the circulation – transformation of things are the same forces that give things value. In short, things circulate because they are valued and it is because they are valued that they become goods"* (Çalişkan & Callon, 2009, p. 389)

Applying the logic of the quote above on construction and demolition waste materials, this means that the way the material is valued now does not let it circulate in a capacity seen as favourable by circular economy principles. Changing that perspective requires intervention from the second key agent – institutional and technical arrangements. These need to be in place to let market participants know what they are dealing with. They enhance the abilities of market participants' cognition and their capacity for action, allowing them to articulate new realities for the given good.

Lastly, the third agent – is the good itself. Construction and demolition waste comes in a myriad of different forms and materials. To be more explicit in my argumentation, I want to focus my efforts on concrete waste materials. The materiality of the material influences its uses and valuation. In the case of concrete, it has different materialities depending on different factors: The chemical make-up of the cement, how its cast, where in the building its located, and how its torn down are only some of the factors that influence the way concrete can be valued. The concrete then has several different valuation modes that all need to be considered to fulfil the economisation process.

If not, then construction and demolition waste materials will remain as waste material rather than valuable goods that can aid in combatting rapid climate change.

5.6.1 The Distinction Between Valuations and Things

Adding to the idea of economisation, Çalişkan and Callon (2010) stress the notion of establishing a distinction between things and the actors capable of valuating them (Çalişkan & Callon, 2010).

Identifying these actors can be challenging, yet Çalişkan & Callon (2010) gives suggestion on which actors are capable:

> *"Such analysis must be inclusive of the effect of actors that are stakeholders in the process of co-performation. A preliminary list whose composition depends on the market under consideration must certainly always include the 'usual suspects': academic economists, management science specialists and, more generally, all of the relevant scholars who are based in university departments and take economy and economic behaviours as a subject of analysis."* (Çalişkan & Callon, 2010, p. 23)

Thus, the authors chosen for literary review, which will be presented further down, play an active role in shaping the perception and calculation of demolition waste materials.

5.7 Circular Economy a New Normal

Circular economy is attempting to "invent" new normative criteria for how the economy would function. Trying to reframe emphasis on material flow and circulation as valuable characteristics in goods. Callon's theory on framing and overflow thus also allows for the analysis of the emerging "new" market and the work academics, institutions, actors, and incumbents alike put into shaping and embedding new practices.

I will, in particular use this thesis to study and structure knowledge on a concrete case study of how materials can be requalified as valuable in the context of circular economy. The findings will be related to an analysis of its implications for adopting the EU Taxonomy directive. I find it relevant to view the EU Taxonomy as a market-shaping device, letting it be studied under the lens of Çalişkan's and Callon's (2010) idea of economisation.

To do so, I will follow actors actively engaged in the reframing of demolition waste materials. Framing and overflowing allow me to observe specific materials and the actors involved in the reframing process, while the theory of economisation allows me to look at how agency shapes the framing process (Çalişkan & Callon, 2009, 2010; Callon, 1998).

Unruh's (2002) theory of lock-in will be introduced in the next section. Helping me categorise some of the initiatives linked to the transition to a circular economy following his theorised change strategies.

5.8.0 Carbon Lock-in and How Lock-in Occurs - Unruh

Re-qualifying construction and demolition waste materials will require qualifying multiple aspects of the material. To understand which aspects need to be understood, I will use the lock-in sources presented by (Unruh, 2002). Before going through the lock-in sources, I first want to demonstrate why I find the theory compelling. Unruh illustrates how lock-in can happen due to Techno-Institutional Complexes (TIC); he uses carbon lock-in as an example. Similarly to the TIC that results in carbon lock-in, it is not inconceivable to suggest that the construction sector suffers from being a TIC that locks-in unsustainable building practices.

Examples that support the claim count; TICs inhibit policy action even in the face of known risks and presence of known feasible alternatives (Unruh, 2002). It has been known for a long time that the construction sector partakes in unsustainable practices, emitting great amounts of CO^2 and waste that is difficult to process, leading to waste going to landfills. Systems that enable concrete use have been integrated with society, such as preferences, expectations, and routines, reinforcing concrete usage. Even though these factors are known, change still seems to be slow and unimpactful, suggesting that the construction sector indeed is a TIC.

5.8.1 Three Generic Policy Approaches

Unruh (2002) presents three generic policy approaches that aim to combat lock-in created by TICs – End-of-pipe (EOP), continuity, and discontinuity (Unruh, 2002). They follow an increasing level of disruption to existing systems and thus allow for a measured response to challenges related to externalities created by TICs.

5.8.2 End-of-Pipe

EOP aims to combat system externalities at the end of processes, leaving the underlying process uninterrupted. Carbon capture and storage is an example of such a strategy, which also illustrates its ineffectiveness in addressing the root cause of the problem. According to Unruh (2002), EOP measures are applied the most in combatting negative externalities from TICs, indicating how powerful lock-in is when it has manifested. EOP measures are already implemented to some degree in the construction sector. In the form of waste sorting regulations, and recycling schemes, however, they fail to enable the reuse of building components and high-quality recycling, e.g., crushed concrete is used as filler for road construction.

5.8.3 Continuity

Next on the disruption scale is continuity measures. They aim to:

> *"(…) modify selected components or processes of the system, but maintain the overall system architecture"* (Unruh, 2002, p. 318)

In using the continuity strategy, practitioners aim to uphold the function of the overall systems, e.g., renewable energy sources that connect to the already established electrical network (Unruh, 2002). Implementing continuity measures in the construction industry has recently gained traction. Design for disassembly is an attempt to adhere to existing practices surrounding concrete use, maintaining the system's architecture. At the same time, changing the output of the system, i.e., reusable building components. Although solving the issue of poor reuse of building components, it still does not address the core issue of rampant concrete use that leads to high emissions. It neither solves the issues related to existing buildings that are usually torn down according to waste sorting regulations.

5.8.4 Discontinuity

Thus, we might be looking at the highest level of disruption needed to solve the issues related to the TIC of the construction sector. Discontinuity aims to *"replace the system entirely"* (Unruh, 2002, p. 318). Examples of discontinuity of systems at the scale of the construction sector are virtually non-existent. According to Unruh, it is due to there being no historical precedents of systems that can match the size of the energy-, construction-, and transportation sector. Unruh does not use the construction sector as an example of TIC of considerable size. I do, however suggest that it is in the same category. As can be seen from the metrics presented earlier, the construction industry has few rivals when it comes to emissions and resource usage.

Bearing this in mind, what would the implication of discontinuation be for the construction sector? One can only guess, as it has not been attempted to implement a plan that aims to discontinue the current systems. However, it would have to be a complete upheaval of current systems, redefining what it *means* to have new buildings, how buildings are built, and how society expects our built environment to look. Perhaps redefining what a city is would not be out of the question either. These would all be questions we would need to consider if a complete discontinuity of current practices is what is aimed for.

5.8.5 Lock-in

To understand the TICs and how to address them, the sources of lock-in need to be understood (Unruh, 2002). Lock-in permeates multiple levels of society and is, therefore, the main driver of keeping the TIC intact. Generating policy responses that align with one of the three generic approaches is dependent on identifying the specific lock-in sources. Knowing the lock-in sources then is paramount to forming adequate responses to TICs.

The justification for using Unruh's theory can be outlined by the logic of creating a new TIC, which is built on the principles of circular economy. To do so, work will have to be done to identify the sources that can aid in locking in these principles. Thus, the sources of lock-in also hold the key to transitioning, as they dictate if something can be locked-in in the first place. To clarify, if circular economy is trying to establish a new TIC, then it would also have to have well-defined sources of lock-in.

The lock-in sources can be split into five categories according to Unruh (2002): Technological, organisational, industrial, societal, and institutional. Thus, circular economy could be established by defining what those five sources entail for circular economy.

- The technological aspect contains examples such as dominant design and standard technological architectures. Highlighting the need to consider the way we design our buildings and the technical know-how tied to the process of building a house.
- The organisational lock-in source relates to routines, departmentalisation, and customer-supplier relations. The implication for the construction sector is that new practices would have to be developed. Further still, the way organisations plan and carry out building processes would have to be reconsidered. While construction workers would have to learn to work with new materials, they are not used to. Agency would probably have to be redistributed among stakeholders to allow for the transition. The most significant impact could face customer-supplier relations, seeing as circular economy proposes completely novel ways of arranging said relation.
- The industrial lock-in source comprises industry standards, technological inter-relatedness, and co-specialised assets. Today's building components do not support design for disassembly, meaning that components such as prefabricated concrete elements would have to change. The building codes do little to facilitate circular building design. Thus they would have to be reimagined.
- The societal lock-in source is comprised of system socialisation, adaption of preferences and expectations. Circular economy principles could have implications for people's relation to their homes, especially when considering new homes. Maybe getting a house made entirely to your liking is no longer possible, and architects would have to face the fact that they can no longer design the house just as they want it, as the material supply would consist of reused components.
- The institutional lock-in source consists of government policy frameworks, legal frameworks, and

departments/ministries. To achieve circular economy, the government would have to change legislation in order to encourage actions that facilitate the transition. The legal frameworks for insurance would have to change as insurance companies will not insure some circular practices.

These examples aim to highlight the complexity of TICs and lock-in. In the analysis, I will attempt to draw a more coherent and precise picture of the transition. Calling upon both the theories of Unruh (2002) and Callon (1998). This analysis can be seen in detail in section 8.9.0

5.9 Following Actors Actively Engaged in the Reframing Process

The framing and overflowing approach request that sociotechnical actors are followed in attempts to reframe or maintain the frame. It is a valuable addition following actors actively engaging in the processes of reframing and qualification to the analysis. The SSC department at Ramboll is currently engaged in said activities, making it worthwhile following their steps in operationalising circular economy. As they navigate the consequences of the taxonomy stepping into effect, how they respond will add context to the research question.

From the interviews and conversations I have had with SSC, I have had the opportunity to observe up close how SSC think and works. To fully articulate how they view the world and to understand their problem-solving skills. The theory on sociotechnical imaginaries will aid in highlighting the thought process and help to give a vocabulary that can describe the activities that SSC partakes in.

5.10 Sociotechnical Imaginaries - Jasanoff & Kim

Sociotechnical imaginaries by Jasanoff and Kim (2009) will aid in understanding the way SSC view problem areas and formulate solutions (Jasanoff & Kim, 2009). Originally the theory helped to explain how governments articulate trajectories for technical endeavours. Sociotechnical imaginaries *project what is desired, good, and worth attaining* in terms of technical developments (Jasanoff & Kim, 2009, p. 123). They are put forth by political actors to justify the selection of development paths and the rejection of others. As the theory states, it can be viewed as a way to project political power. It requires political will and support to achieve the goals set forth by the sociotechnical imaginary. Gaining support for the desired sociotechnical imaginary involves the negotiation of stakeholder roles, allocation of funds, and investments in the required infrastructure to support the technical development path. Sociotechnical imaginaries have the potential to influence and permeate the very fabric of design and technical development, which might result in a reconfiguration of the social and political interpretation of the related issue.

The main reason for choosing this theory rests on the presumption that imaginaries are comprised of “*an organised field of social practices*”. If we extrapolate that presumption, the construction sector can be seen as imaginary (Jasanoff & Kim, 2009). While attempts to alter it, such as circular economy and the EU Taxonomy, are desirable versions of the future.
The forthcoming analysis will utilise sociotechnical imaginaries to situate the visions of circular economy and the EU taxonomy for sustainable activities. Seeing as both can be expressed through the wishes of future investment and development (Jasanoff & Kim, 2009).

As Sociotechnical imaginaries can aid in discovering which stakeholders need to be activated, it complements the following of actors in the framing-reframing process presented by (Callon, 1998). Furthermore, using imaginaries to highlight which qualities are essential to which actors should show how the framing could align with different stakeholders. While also shedding light on the more extensive sociotechnical networks that need to be stabilised to implement circular economy.

Additionally, as the European Union is gearing up to implement their new taxonomy for sustainable activities, sociotechnical imaginaries should help situate the initiative in a greater political and transitional context. The taxonomy aims to facilitate green investments and impede greenwashing, thus projecting a sociotechnical imaginary. Both from the definition presented above and using the more specific definition given by Jasanoff & Kim (2009):

> *"sociotechnical imaginaries as we define them are associated with active exercises of state power, such as the selection of development priorities, the allocation of funds, the investment in material infrastructures, and the acceptance or suppression of political dissent"* (Jasanoff & Kim, 2009, p. 123)

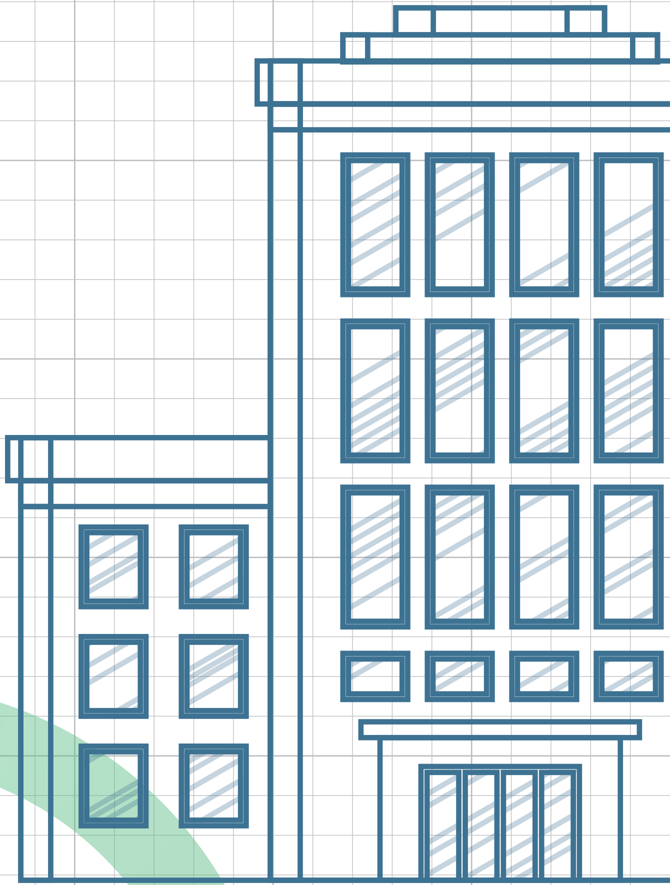
5.11 Summary of Theoretical Findings

In conclusion, the findings from the presentation of the theory will allow me to analyse the subject area from a certain point of view.

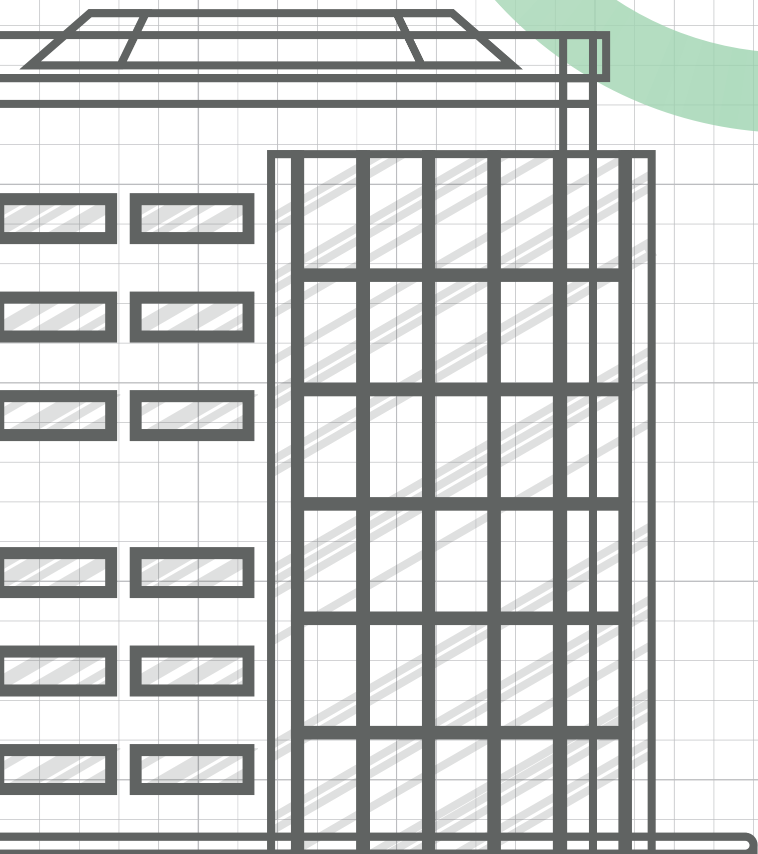
Several observations work to establish a framework for further analysis. First, I have demonstrated that the linear acceleration economy enables over-consumption of primary materials, leading to the depletion of planetary resources (Rosa, 2013). Furthermore, using the theories of Callon (1998), Geels (2002) and Çalişkan & Callon (2009, 2010) to situate the transition to a circular economy within the realm of sociotechnical transitions through actor involvement and active deployment of agency. Additionally, the theories let me investigate the process of qualifying and re-qualifying specific materials, such as concrete waste material.

Secondly, Jasanoff & Kim (2009), Callon (1998) and Çalişkan & Callon (2009, 2010) all demonstrate how the academic community plays a vital role in bringing about change. Jasanoff & Kim (2009) points out that "*imaginations can penetrate the very designs and practices of scientific research and technological development*" (Jasanoff & Kim, 2009, p. 124). Callon (1998) points to the scientific community's involvement in the framing and qualification of goods (Callon, 1998). While Çalişkan & Callon (2009, 2010) highlight the influence the academic community exerts on market dynamics:

The influence of the academic community will be explored further in the upcoming section, which will consist of a literary review of contemporary literature on circular economy in the construction sector. The literature review will act as context for the chosen theories and aid in answering the problem formulation.



Part 3
Literary Review



6.0 Introduction to the Literary Review: The Academic Community's Assessment of Circular Economy

In the following literary review, I will present contemporary literature on the adoption of circular economy in the construction sector. The review will revolve around the different strategies and aspects that make up circular economy. The literary review is comprised of several different authors, whom all work to quantify and contextualise the transition to a circular economy.

6.1 Literary Review

The following section will outline which areas are well understood and where the literature seems to be lacking. While the literature review cannot be seen as exhaustive, it should aid in describing the main themes of this subject matter.

The literary review is comprised of contemporary articles, with the oldest being published in 2017. Most articles were published in the *Journal of Cleaner Production*. *However*, journals such as *Resources, Conservation and Recycling* and *Buildings* also contributed profoundly.

Circular economy is one of, if not the most promising alternative to our current way of living. Offers solutions to how we can decouple financial growth from resource extraction and usage (Circle Economy, 2022; Kanters, 2020; *What Is a Circular Economy? | Ellen MacArthur Foundation*, n.d.). However promising circular economy might be, the philosophy behind it is only that, a philosophy. Making circular economy easy to project onto different sectors and industries, the difficult part is implementing the philosophy into a cohesive framework that everyone agrees on. Several scholars are looking at the state of circular economy in the construction sector, approaching the subject from a multitude of different angles. Trying to decipher what is currently being done, what works, what does not, and where to go in the future. After going through multiple articles, five of which are literary/systemic reviews on the subject matter, it seems clear that no consensus has been reached on best practices, development paths, etc. The literature does start to paint a picture of which areas seem most promising and what research needs to be done.

6.2 Contemporary Literature on Circular Economy in the Construction Sector

It might seem reluctant to mention that the construction sector is responsible for an unfathomable amount of resource extraction and waste generation. Nonetheless, the articles presented in this literary review mostly start with that very introduction. Outlining numbers that, even though they are described several times, seem surreal every time they are read (Benachio et al., 2020; Circle Economy, 2022; Eberhardt et al., 2019; Kanters, 2020).

One of the consequences of this massive consumption and use of materials is that we have building materials all around us. Scholars are increasingly looking at our cities in general and our buildings in particular as material banks (Arora et al., 2020). Different schools of thought are present in the literature; some take outset in current practices (Ghisellini et al., 2018), while others try to look at future practices that can enable circular economy (Eberhardt et al., 2019; Hossain et al., 2020; Kanters, 2020).

For the sake of not over scoping this thesis, it is vital to distinguish between the different types of circular economy in the literature. A number of the articles focus on non-structural components such as tiles, flooring, toilet fixtures, windows, doors, etc. (Arora et al., 2020; Stephan & Athanassiadis, 2018). They typically look at the harvesting and reuse of said materials. The number of articles I have chosen that brings this perspective is relatively small as I have decided to focus on how circular economy can affect structural components as the scope of this thesis. I found Arora et al. (2020) quite helpful, as they develop a framework for estimating potential recovery and reuse of building components that are appliable to non-structural and structural components. They chose to focus on non-structural components, but that does not invalidate the framework (Arora et al., 2020). While I will not apply the framework presented by Arora et al. (2020), the way they view buildings and their circularity is very approachable and easy to put into context.

6.3 Understanding circular economy in the construction industry

As stated previously, circular economy is a philosophy that can be applied in different settings, meaning that circular economy solutions in, e.g., the textile industry will not be the same as solutions in the construction industry. Determining which circular economy principles define the construction industry will be paramount in pushing the industry forward. Without clear indicators or standards, circular economy will remain a diffuse concept that is studied rather than a robust framework that can enable real change.

There seems to be a consensus among scholars that the 3R principle (*reduce, reuse,* and *recycle*) is central to understanding how to deal with construction and demolition waste materials (C&DWM) (Ghisellini et al., 2018). The 3R principle informs circular strategies, with literature dedicated to analysing recycling flows (Ghisellini et al., 2018) and reuse logistics (Eberhardt et al., 2019). Less of the chosen literature focuses on the reduce aspect, as reduce relates to reducing the amount of material used to start with or the amount of waste. Reasons as to why that is the case could be but are not limited to; (i) I had specifically searched for literature focused on recycling and reuse, (ii) *Reduce* strategies start before waste is generated e.g., design for disassembly, and designing buildings that use less material, (iii) *Recycling* and *reuse* leads to a reduction of waste, making *reduce* an organic part of the other two.

In using the 3R principle, it is important to distinguish between recycling and reuse, two terms often used interchangeably in everyday language. The distinction between the two:

- Recycling: Material that, after harvesting is re-processed into a new material/products
- Reuse: Using material/components without altering their shape, composition etc., i.e., use the same thing for another purpose.

6.4 Dissensus on What Should be Measured

In determining which strategies are most impactful, performance indicators are crucial. Better performance indicators lay the foundation for informed decision-making. Choosing the proper performance indicators can be challenging, as both too simple and too complex indicators can skew the results in the wrong direction. As already stated, the construction sector is a heavy consumer of resources and emits large proportions of global GHG emissions. Understanding the underlying factors that enable this resource use and these emissions is central to curbing the development. It is quite evident that the authors of the chosen articles think the same thing, as they nearly all deploy or at least mention the use of tools like Life cycle assessment (LCA), Life Cycle Costing (LCC), Material Flow Analysis (MFA), Building Information Modelling (BIM), and Energy Accounting (Akanbi et al., 2018; Ghisellini et al., 2018). I will not go into detail with each of them, as that would add unnecessary complexity to this overview. However, the names of the different measuring methods give some valuable insight. Apart from the LCA and LCC, which both stem from the life cycle perspective, they measure different things. Which results in different results and interpretations; one model could yield favourable results, while another would show negative effects for the same project. Choosing the suitable measuring method is not the only thing that influences outcomes. The phases of the building project included in the analysis also affects the results.

As both noted by Ghisellini et al. (2018) and Benachio et al. (2020), especially the frameworks that are based on life cycle thinking, have discrepancies between their approaches. They can be used in several different perspectives, such as *cradle-to-gate*, *cradle-to-grave*, and *cradle-to-cradle*, which all consider either some or all phases of a building's life cycle. As circular economy aims to feed materials into new processes, and in line with the authors of the chosen literature, cradle-to-cradle seems best in supporting circular operations. Frameworks that can underpin and calculate the building process are necessary to map all impacts and aid decision-making in the building process. And to a further extent, calculate the materials transferred from a building project into a new process as new material. Doing this negates some of the uncertainty linked to some of the other methods. Both cradle-to-gate and cradle-to-grave suffer the issue of invisible externalities that is not considered.

Similarly, the other mentioned frameworks suffer from the same lack of externality consideration. BIM is a well-rounded tool and will be helpful in transitioning to circular economy, but it only relates to one building so that externalities will remain invisible (Akanbi et al., 2018). Its abilities to act as a planning tool will be discussed further down in this thesis. MFA suffers from some of the same issues, as it needs to be used around well-defined systems. The supply chain for the construction sector is claimed to be very complex and ill-defined, making MFA hard to apply to identify all externalities. It will be useful in relation to the EU taxonomy, as it sets requirements for recycled, reused, and renewable materials; having an overview of the inflows of material is crucial to aligning to the taxonomy.

6.5 Recycling

Recycling refers to gathering waste materials that would otherwise have been thrown away. I will use the categorisation of waste materials used by Ghisellini et al. (2018) throughout this paper (Ghisellini et al., 2018). Waste material is generated both under construction of new buildings and during demolition – referred to as construction and demolition waste (C&DW). C&DW is an umbrella term and does not tell anything about the composition of the C&DW. In the EU, C&DW mainly consists of bricks and concrete (80-83%), while the remaining part consists of a myriad of different materials, e.g., packaging, wood, metal, paper, rocks (Ghisellini et al., 2018). Separating C&DW into homogeneous material factions yields better secondary materials, as they are easier to process under recycling – thus, homogeneous C&DW factions are called construction and demolition waste materials (C&DWM) (Ghisellini et al., 2018).

As Ghisellini et al. (2018) present in their literary review, recycling of C&DWM is the most researched circular economy strategy (Ghisellini et al., 2018). The authors offer a comprehensive comparison of LCA results from various articles spanning multiple functional units and materials. The authors cite several different case studies and LCA approaches, resulting in somewhat too specific results, as they cannot be applied generally. They do, however, offer the most comprehensive review of different approaches and results. Some of the reviewed material is outside of the scope of this thesis, such as reuse/recycling scenarios for construction waste aiming at off-setting emissions from the construction. The literary review by Ghisellini et al. (2018) succeeds in showcasing the intricacies of circular economy in the construction sector, outlining multiple points of view in terms of C&DWM life cycles:

1. Buildings that reuse/recycles C&DW at end-of-life to offset emissions during production-phase and use-phase. Could, in some scenarios, reduce contribution to climate change of the building by 77% (Ghisellini et al., 2018).
2. Reuse/recycling of demolition waste, going towards maximum recycling reduces GHG emissions the most while going towards maximum reuse reduces energy consumption the most. Claims projects featuring concrete heavy buildings would benefit most from recycling schemes (Ghisellini et al., 2018).
3. Recycled concrete aggregate, the studies presented show that recycling concrete is a better alternative than using natural concrete aggregate in an EU context

Although recycling is better than landfilling/incineration, no conclusions can be drawn about recycling versus reuse pathways. As the authors themselves state:

> *"(…) the sustainability of reuse/recycle is a site-specific outcome and the hierarchical importance of reuse and recycling as well as of incineration over landfilling cannot be predefined at [sic] priori"* (Ghisellini et al., 2018, p. 636)

I want to caveat the usage of mainly Ghisellini et al. (2018) in the above section that not a lot of the chosen literature handles recycling. I will touch upon why I have not chosen to focus my efforts on recycling literature later in this thesis. I did find it necessary to outline and describe the different schools of thought and approaches. Considering that recycling is the prevailing practice of the construction industry today due to legislative and economic enablers. I find it necessary to have a vocabulary in place to discuss, describe and analyse the difference in approaches to recycling.

6.6 Reuse

As stated previously, reuse refers to products kept in a condition that allows the product to maintain its original form after harvesting. Reuse is a fundamental part of CE, as the product is held at the highest possible value for as long as possible (Eberhardt et al., 2019). The principle should be the main priority in most construction and demolition projects. Yet, most authors point out that the industry has a hard time adopting principles into tangible action (Kanters, 2020). There is no clear culprit identified in the literature, though certain themes start to be recognisable across the different authors' articles. First, there is a clear difference between reusing structural and non-structural components, the former being relatively more manageable than the latter. Non-structural components count doors, windows, bathroom fixtures etc. they are easily removed without damaging the products.

Structural components, on the other hand, are a very different story. Compared to recycling, which can be initiated during construction *and* demolition, reuse of structural components can only be initiated during major renovations or at the building's end-of-life (Eberhardt et al., 2019; Miljøstyrelsen, 2018). Buildings due for renovation work or demolition are likely to be quite old, as the lifespan of a building can be anywhere between 50-300 years. Meaning they were built during a time when architects were not designing buildings with circular economy principles in mind. The consequences of buildings not being designed to support the reuse of their components are that it is tough to do so (Arora et al., 2020). Despite being difficult, it is not impossible, and scholars are increasingly trying to figure out how to facilitate the reuse of structural components best.

6.7.0 Identified barriers to reusing structural components

In terms of reusing structural components, it is not at all a common practice in the construction industry. Although it is quite clear from the literature that the reuse is not being done at scale yet, there is a lack of the authors stating that it is a technical issue. Eberhardt et al. (2019) claim that structural concrete elements can last for at least three lifecycles, and practices to allow that to happen are not established. In the following section, I will present the barriers to adopting reuse practices that have been identified in the literature.

6.7.1 Economy

The construction sector is a highly competitive industry with low profit margins and is said to be conservative in its willingness to adapt to new practices/technologies (Kanters, 2020). Thus, asking industry players to take on additional costs without offering compensation is a challenging task. As it stands now, demolition costs rise considerably if consideration and harvesting of reusable components need to be included in the process (Miljøstyrelsen, 2018). With most of the literature pointing toward the economic incentives and lack thereof as one of the biggest barriers to progress (Ghisellini et al., 2018). A sub-issue related to economic factors is the question of insurance. Even though stakeholders wish to build with reused components, the insurance framework to cover the different approaches is lacking (Eberhardt et al., 2019).

6.7.2 Construction Projects

The way construction projects are planned and carried out makes harvesting reusable components in buildings very challenging (Benachio et al., 2020; Eberhardt et al., 2019; Kanters, 2020). Furthermore, there is put an emphasis on how and who is given agency in project planning; the right set-up could make or break the possibility of gathering reusable components (Kanters, 2020). Suggestions on how to solve the issues surrounding the way construction projects are set up count; greater collaboration between stakeholders (Arora et al., 2019; Eberhardt et al., 2019), shifting focus toward designing for disassembly and lending more agency to the planning and procurement of the building (Kanters, 2020).

6.7.3 Managerial Challenges

As a consequence of the challenges mentioned above in construction projects, managers have difficulties adopting frameworks to accommodate the harvesting of reusable components. There is a lack of knowledge from decision-makers to apply measures to their companies and projects.

Knowledge in this regard does not refer to technical know-how, which, as established above, is present. Instead it refers to the way stakeholders internally in construction companies and externally in planning projects align and plan out projects in a way that would allow for greater reuse. Leading to consensus among some scholars that there is a need for clarification of what circular economy entails and which indicators should be used (Benachio et al., 2020; Eberhardt et al., 2019; Nuñez-Cacho et al., 2018). Further still, questions pertaining to the application of the technical knowledge, i.e., what situations call for demolishing with either recycling or reuse in mind. The lack of knowledge stifles attempts to transition, as managerial systems and governance are difficult to establish.

6.7.4 Material Passports

Not knowing what is inside the building before it is torn down could be the single greatest obstacle to an efficient reuse scheme. When uncertainty is present, coordination between demolition sites and construction sites cannot happen. Material passports would solve this issue, as stakeholders would know what materials a building contains and the condition of said materials. However, as pointed out in the systemic literature review by Benachio et al. (2020), it is an underexplored area of research. Only the interviewed architects in Kanters (2020) article mention material passports as an option in the selected literature.

6.8 Using the chosen literature to define circular economy

To answer my problem formulation, more specifically, the requalification of demolition waste, I need to identify which aspects influence materials' circulation. I found the six aspects outlined by Pomponi & Moncaster (2017) useful in this endeavour. They are as follows: Governmental, economic, environmental, behavioural, societal, and technological. They align well with the lock-in sources from Unruh (2002) and thus lend credibility to the proposed idea of using them to enable a transition to a circular economy.

In addition, Nuñez-Cacho et al. (2018) circular economy indicators are shaped to allow individual companies to probe and govern their circular economy performance. The indicators are more concrete, but I would argue that, e.g., energy management is informed by the six aspects presented by Pomponi & Moncaster (2017). Although distinct, they complement each other and will allow for both, looking at bigger picture dynamics such as the economy and legislation and individual practices/technologies. The conjunction of the two gives a perspective that I find useful in analysing the impact of the EU taxonomy. Reason for why I find the coupling compelling is the fact that the taxonomy puts requirements for the use of both recycled and reused material. As previously described, they are core components to achieving the transition towards circular economy in the construction sector. Requalifying the demolition waste material would therefore need to happen with respect to the lock-in sources. My attempt and contribution to the requalification of demolition waste materials will be described further down in the analysis, the results will be presented and discussed, and finally, I will offer my conclusion on the endeavour.

6.9 Summary of findings of literary review

In going through the literature, it has been established that the 3Rs are a core component of CE, especially in relation to the construction sector. To render the 3Rs, an effective strategy, five aspects need to be considered: Technological, organisational, industrial, societal, and institutional (Unruh, 2002). Furthermore, it has been found that there are suitable indicators that relate to specific buildings that can help determine how the requalifying of demolition waste materials can happen by the five lock-in sources aspects.

In terms of recycling and reuse, recycling is the most adopted approach to accommodate circular economy principles. Recycling is made possible due to the way buildings are designed and torn down; further exacerbating recycling is the fact that there are strict regulations tied to waste sorting in the EU. On the other hand, reuse suffers as buildings are challenging to assess for reusability. Knowledge on (re)usable components in already built buildings is virtually non-existent at scale.

While promising in terms of technical feasibility and combatting rapid climate change, the structures to enable the reuse of structural components are lacking. Business models need to be developed; the same is the case for legislation and managerial know-how. Furthermore, the way construction projects are planned and materials are procured works against the implementation of reuse practices. These insights form the basis for my further work, as I find the lack of possibilities detrimental to the adoption of circular economy. It is imperative that the construction sector finds solutions to the challenges related to reuse. As demonstrated, recycling practices are far more well-established, with solid waste sorting paradigms and effective value chains.

There is undoubtedly still an immense challenge in securing the best possible recycling configuration for the construction sector. Yet, recycling is primed to feature more prominently in the future construction sector. Thus, the following sections will focus on the requalification of concrete waste with reuse in mind.

Part 4
Findings

7.0 Analysis and Findings

7.1 Introduction to Analysis and Findings

To contextualise the forthcoming sections, I want to outline the argumentation made up until this point. Summarising the findings from applying the theories and the analysis of contemporary literature. Additionally, I want to outline which elements I will bring into play and their role in contributing to answering my problem formulation.

Having established that the European Union's Green deal is a sociotechnical imaginary, the EU taxonomy for sustainable activities falls under it. The EU Taxonomy mainly acts to shape markets and exerts pressure on implementing circular economy principles. Additionally, by deploying Rosa's (2013) theory of social acceleration and Geels' (2002) theory of MLP, I have showcased that not only is circular economy in direct opposition to the linear capitalistic economic system, it cannot be categorised as either a part of the regime or the niche level of technical transitions.

As circular economy is a new way of knowing markets, the goods circulating on those markets need to be known in new capacities. Making it favourable to call upon the theories of Callon (1998) and Çalişkan & Callon (2009, 2010) to understand the actors involved in the re-framing process of demolition waste materials and the actors involved in stabilising the framing of demolition waste materials – including, as actors, the scholars chosen for this thesis. Hence, the choice to focus on the reuse of demolition waste materials, as the scholars point to it being an area of concern, using the lock-in sources of Unruh (2002) to identify the aspects of requalification for the reuse of demolition waste concrete.

An analysis of the sociotechnical imaginary of the EU taxonomy will be given to determine whether the targets set by the technical screening criteria of the EU taxonomy are attainable. As I argue that the EU taxonomy creates pressure on stakeholders within the industry to transition, the work Ramboll SSC conducts will be analysed according to the theory of sociotechnical imaginaries.

As has been showcased in the literary review, reuse practices are especially poorly implemented throughout the construction industry, leading to the choice of focusing this analysis on identifying and describing specific aspects of requalifying concrete waste materials to allow it to circulate in a reuse capacity on the market. To do so, I will introduce a design game that aims to test assumptions, further expand my knowledge, and gather intel on Ramboll's role in the transition.

Lastly, I will use the insights from the design game in conjunction with the insights gained from applying the theories and the literary review to build a specific classification of requalifying aspects for concrete waste materials to cultivate reuse.

7.2 Viewing the EU Taxonomy as a Sociotechnical Imaginary

The transition towards a more sustainable future comes in many different shapes and sizes. While stakeholders try to negotiate the terms of the transition, various agendas and trajectories emerge and disappear as terms and conditions get continuously negotiated. Bringing the theory of sociotechnical imaginaries into play to analyse and contextualise the new EU Taxonomy will help situate circular economy in a broader sociotechnical imaginary. Which then allows for the understanding of which elements influence the sociotechnical imaginary of circular economy.

7.3 The sociotechnical imaginary of the EU taxonomy

The European Union has envisioned a future where it has reached its sustainability goals – the European Green Deal. In doing so, conjuring up a sociotechnical imaginary of an immense scale. Composed of eight different action areas aimed at the three pillars of sustainability – economic, social, and environmental (*A European Green Deal | European Commission*, n.d.). The Green Deal aims to ensure a just and effective transition. Although both impressive and exciting in its own right, the scope of this thesis - as stated in Approach and limits of scope - does not allow for a thorough analysis of the entire Green Deal. Thus, I find it sufficient to acknowledge the EU Taxonomy as being a part of a larger sociotechnical imaginary without resorting to analysing the whole overlying structure of the Green Deal.

The EU Taxonomy's core aim is to direct funds towards recipients deemed in line with what is considered sustainable activities. The reason for this wish is the observation of two social factors; (i) There is growing interest in investing sustainably from the public and financial institutions, and (ii) Lack of transparency in sustainability claims can lead to greenwashing.

One could argue that the EU taxonomy exhibits several of the traits outlined in the introduction to sociotechnical imaginaries. The exercise of state power through development priorities is evident since the purpose of the EU Taxonomy is to foster green development. Furthermore, the EU aims to direct funding towards taxonomy aligned activities, while the technical screening criteria denote where material infrastructure ought to be developed. Lastly, with the recognition of rapid climate change and depletion of planetary resources as threats, the EU suppresses political opposition such as climate change deniers and stakeholders who claim that the free market can solve climate change. The EU actively shapes the social practices relating to the transition towards a more environmentally and climate-friendly economy. They do so by denoting six key objectives as outlined earlier; all six contain parts of the EU's sociotechnical imaginary. For now, I want to focus on the circular economy objective.

It comes naturally that circular economy is included in the sustainable activities regarded as fundamental to achieving the EU's sociotechnical imaginary. As described earlier, circular economy is lauded by academics as a promising alternative to our linear acceleration economy.

Circular economy is not a homogeneous concept; it means different things to different stakeholders. Especially when it comes to other sectors, the EU has attempted to define what it means to contribute to circular economy in the construction sector through its taxonomy. However, as has been showcased in the literary review, several different points of view are present in the contested 'arena' of making sense of a circular economy.

The following section will outline the EU's definition of circular economy and how I view it as an underlying sociotechnical imaginary to the whole EU Taxonomy.

7.4 Viewing the technical screening criteria for substantial contribution toward the transition to a circular economy as a part of a sociotechnical imaginary

Contrary to the overlying objectives of the EU Taxonomy, the technical screening criteria do not cater to the aspects of political power projection. Instead its aim is to lay the trajectory of technical developments. Thus, viewing it as its own sociotechnical imaginary would be fallacious, yet it underpins and lends legitimacy to the EU's sociotechnical imaginary. The technical screening criteria of the EU Taxonomy act as the EU's translation of how they view circular economy as a concept. Setting boundaries for where the 'playing field' is for other actors and, in that way exuding political power to stakeholders navigating the arena of circular economy.

Keeping this notion in mind, it is not outrageous to suggest that the EU Taxonomy manifests a top-down pressure on stakeholders and incumbents alike. The observation stems from the fact that the sociotechnical imaginary of the EU Taxonomy's six objectives permeates several different arenas of technical and social development. One of them being the arena of circular economy; despite the top-down pressure, circular economy is not solely defined by the EU. As mentioned earlier, circular economy means many things to many stakeholders.

This can be seen from the general focus on recycling practices and use of renewables, as has been described in sections 6.0 through 6.9. Furthermore, the sections highlight the need to understand reuse better.

7.5 The Social Imaginary of SSC

I have to concede that Ramboll and, to an even lesser extent, SSC have the same political power and agency as governments. However, they occupy a similar role within the reality they are situated in. As Ramboll carries considerable agency within the industries, they operate in, together with the fact as they usually act as advisors for multiple stakeholders, they have the ability to articulate possible futures. By understanding the needs of various stakeholders within a given field, coupled with understanding technical issues and future wishes. SSC can engage in sociotechnical imaginary building.

As the interviews with my collaboration partner revealed, they attempt to operate in the same capacity as governments, making it favourable to view their work from the point of view of sociotechnical imaginaries. The trajectories that need to be cultivated to transition to circular economy principles can be expressed through sociotechnical imaginary. The reason for this is that circular economy is an expression of what is good, desirable, and feasible, needing stakeholder mobilisation, infrastructure investments, and the configuration of markets to be successfully implemented.

The interviews were especially focused on the *Do-no-significant-harm* criteria in the climate mitigation part of the Taxonomy introducing achievable thresholds for circularity percentages. Forcing market players to build with circular materials when building new buildings. Hence, the conversation revolved around the consequences of said addition and how affected stakeholders should respond – which I see as an attempt to assemble their sociotechnical imaginary.

The state of their sociotechnical imaginary will be explored further by introducing a design game, which will be discussed in the next section.

8.0 The Requalification of Concrete Waste Material

In the following chapters, I will outline how I used a design game to explore the underlying aspects of the lock-in sources and test my assumptions. Then the empirical data will be collated with the findings from the theoretical frameworks and results from the design game to produce a comprehensive examination of the requalification of concrete waste materials to foster reuse.

8.1 Design game

In the following section, I will present the work that I have conducted in exploring the implications of my findings through the design and deployment of a design game and the design games themselves (Figures 4 & 5). The design game was designed to test out the existing knowledge that I have acquired—using the interview to determine where Ramboll focuses its efforts and test out the presumptions I have made.

Design games enable the designer to gather and explore stakeholders' interests and concerns, as it creates a space suspended in an imaginary world where normal circumstances do not apply. It allows the participants to contextualise past and current experiences within the realm of the design game (Vaajakallio & Tuuli, 2014). Hence, the designer's job is to set the boundaries for which realities must be explored. Unlike ordinary games, there are no prescribed rules to design games. However, they should offer the possibility of discussing the subject matter under investigation. Thus, a large part of designing the game is considering which stakeholders to invite and which subject matter details can and should be negotiated.

Additionally, it should preferably align with the invited players' expertise to maximise the possibility of players relating and interacting with the game. Deciding on the form and function of the design game is a big part of achieving valuable insights. Seeing as there are no predetermined rules or structure of a design game, the usage and desired results dictate the game's characteristics. The characteristics of the design game determine which type of game it is, as there exist several different 'genres' of design games (Vaajakallio & Tuuli, 2014). I used the design game in the context of exploring future alternatives to current practices, inviting a specialist from Ramboll Buildings to join me in exploring possible futures (Brandt et al., 2008).

The game was based on my interpretation of a construction project flow and Unruh's (2002) lock-in sources. The construction flow was critical to the design game's look and function, as the implications of reusing components are subject to which phase of the project is considered. Furthermore, it allowed me to prepare for different possible outcomes, as I did not know which phases of construction projects the participant was associated with.

The design game was split into three parts, the first aimed at exploring possible scenarios for the reuse of concrete elements. Which should help envision future alternatives to current practices (Vaajakallio & Tuuli, 2014). The second part of the design game was an alternative version of the first design game which was configured with my ideas of how future practices would look, exploring the *"as-if-worlds"* I had envisioned (Brandt et al., 2008, p. 57). The last part was a little less detailed than the other two parts, seeing as I wanted the specialist from Ramboll Buildings to answer from *'the top of his head'*. The game was comprised of five categories corresponding to the five lock-in sources. The goal was to see what initially crossed his mind when asked to think about the five lock-in sources. I hoped it would lead to natural responses that I could not influence.

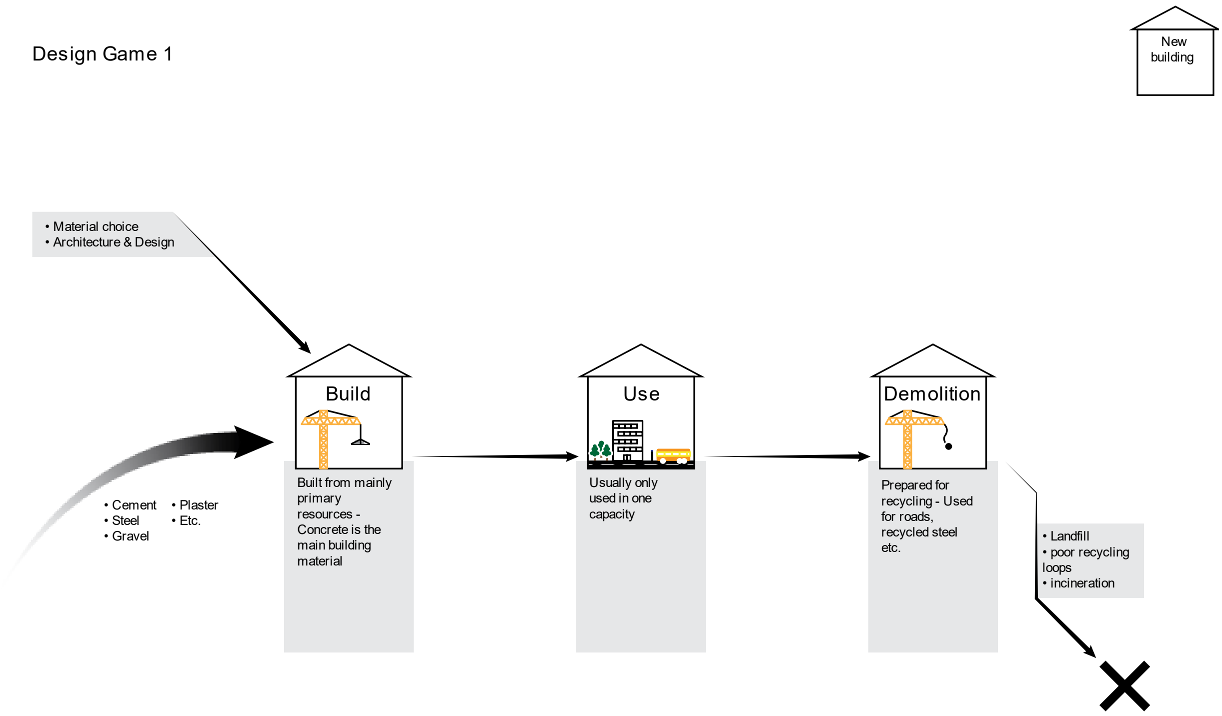


Figure 5: Design game 1 - Made by me

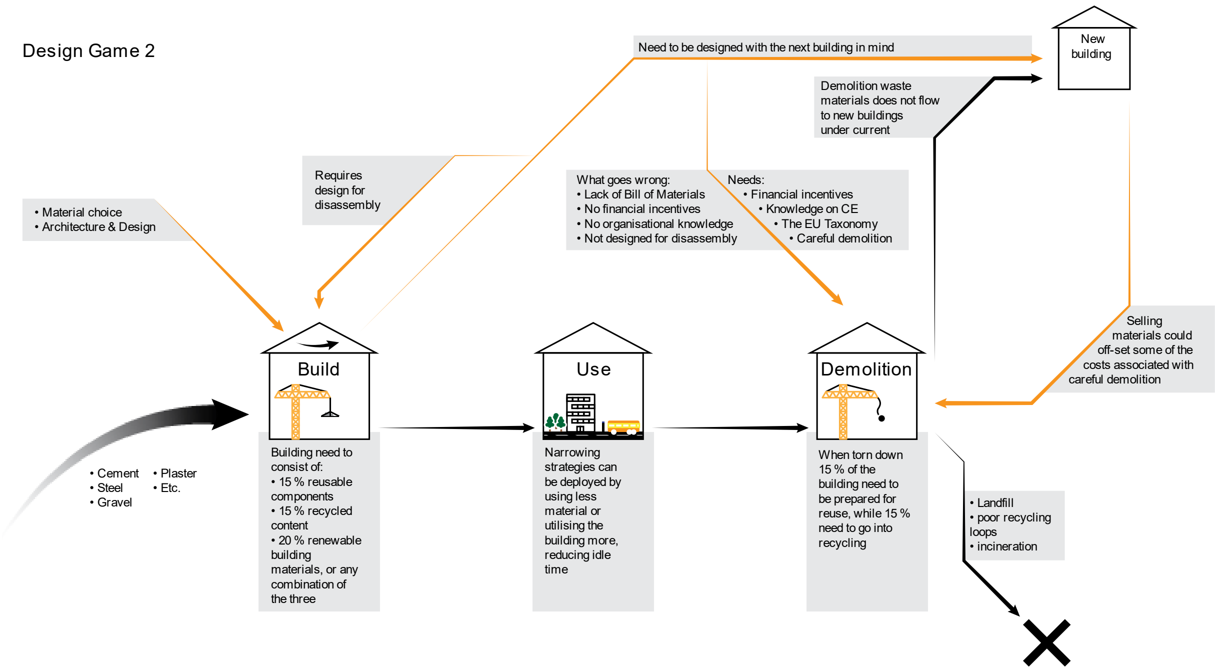


Figure 4: Design Game 2 - Made by me - Madsen (2022)

I did not have the opportunity to facilitate the workshop in person, so the intervention was held online in Miro, as seen in the game's design. I made an effort to give the player as much freedom as possible, enabling him to edit on the Miro board. However, the online format was limited by different factors, which will be discussed in the summary and discussion of the design game.

8.2 Results of the design game

The interview started with a brief introduction to the focus of this thesis and the purpose of the interview. I explained that the objective was for him to consider which elements would be needed to facilitate the reuse of components in new buildings – as can be seen in game 1, it is an empty canvas. As mentioned previously, I was curious to find out which phase of the construction project the participant was associated with.

Hence, one of the objectives of the design game was for the participant to explain how he worked with construction projects in particular and circular economy in general. The player was asked to place ‘elements’ that would enable the reuse of components above the corresponding phase. Subsequently, we would move on to the ‘complete’ picture, where the aim was to identify possible oversights and mistakes in my interpretation.

Before we started ‘solving’ the game, he explained that he mainly worked with construction projects' design and planning phase. Although, his teams also had assignments looking at the operational aspects of portfolio management. Lastly, his team had just gotten their first assignment determining the material composition of a building due for demolition.

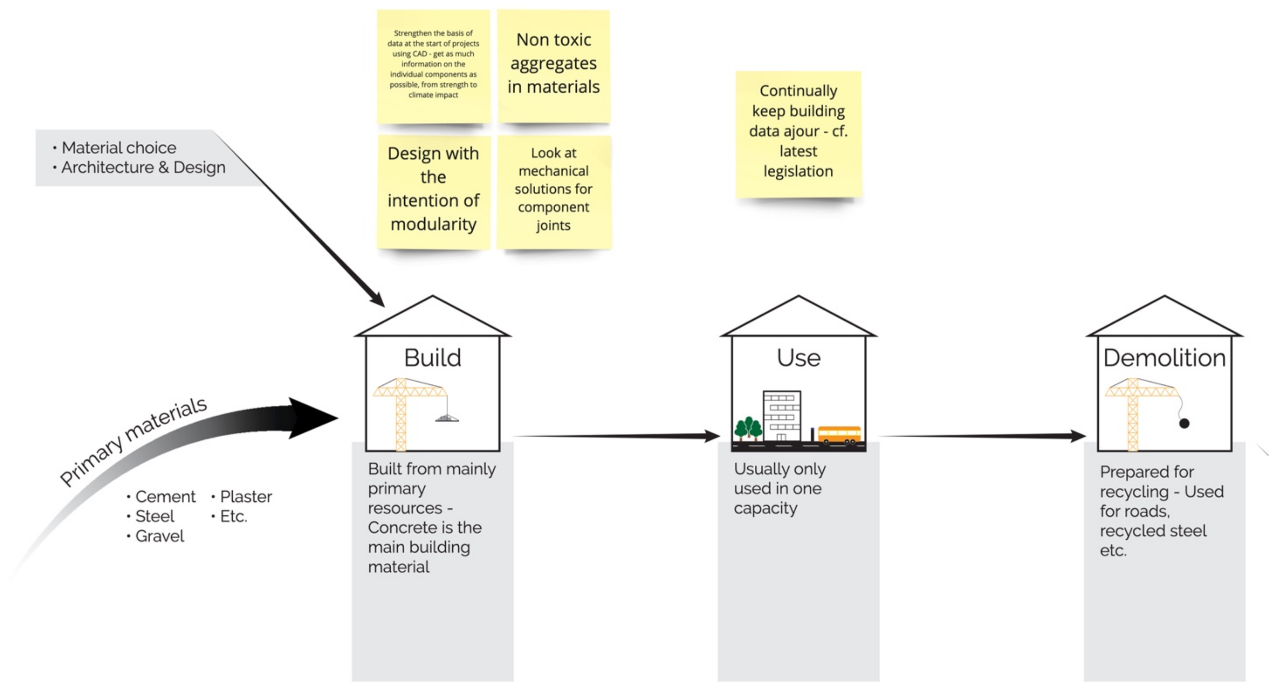


Figure 6: Answers from part 1 of the design game - Madsen (2022)

8.3.0 Part 1: The empty canvas

8.3.1 Insights on the build phase

I have translated his answers into English

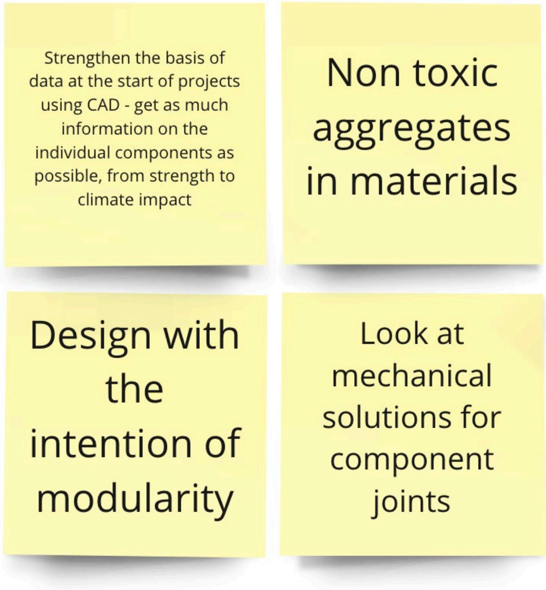


Figure 7: Answers related to the building/planning phase

The main focus of his work was concerned with the design and planning of new buildings. The prevalent theme of his approach was to consider how new buildings could accommodate the circular agenda rather than approaching the issue by facilitating the reuse of components from old buildings. The four post-its he placed in the build/design phase are a testament to that approach since none of them addresses current issues correlated with the demolition of buildings. Despite all four post-its being highly relevant in achieving a circular building sector, the participant did not explain how demolition waste might get reused. The participant emphasised that he thought those four aspects were paramount in furthering the circular agenda.

8.3.2 Insights on the use phase

Figure 8: Answer related to the use phase

His replies related to the building phase emphasised ideas that aligned with building new circular buildings. Perpetually keeping building data up-to-date is only possible if the data is available. The way construction projects are conducted today results in building data being lost. Thus, it does not present a solution to the challenge of reusing components.

8.4 Part 2: Checking my interpretation

The second part of the design game kept with the theme of the last part, as suggestions from the participant mainly focused on new ways of designing buildings. Although, it became evident during the dialogue that the participant was well versed in circular principles, as he suggested the narrowing strategy of limiting 'idle' time for buildings. He mentioned that buildings could potentially use less material, as it is not unusual to build with a safety factor of ten people per square meter. Suggesting that building codes and practices were ingrained with a *better safe than sorry* approach, leading to excessive amounts of embedded carbon in the concrete structures. Lessening the requirements by just a few percentage points would have trickle-down effects throughout the project, as it directly correlates with the amount of concrete used.

He mentioned two factors that could potentially have implications for the reuse of components. Firstly, he said that upcoming legislation on carbon emissions during construction could result in the reuse of components. Complying with the legislation hinges on if new types of concrete become available; consequently, if it does not, entrepreneurs would have to look elsewhere to achieve the carbon limit set – e.g., reusing old components. Secondly, he also mentioned that the usual practice of conducting LCC calculations does not include the residual value of building components at end-of-life. Hence, there is a possibility that if it were to be included, it could promote a viable business opportunity for reusable components.

8.5 Part 3: Responding to lock-in sources

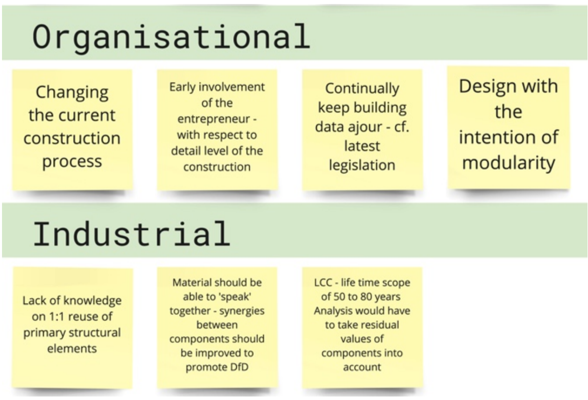


Figure 9: Answers from part 3, mainly fell under the organisational and industrial lock-in sources

The last part of the design game focused on the five lock-in sources outlined by Unruh (2002). His argumentation aligned well with the rest of the interview, focusing on aspects that would let new buildings become more circular. His answers expanded on the conversations we had in parts 1 & 2. He only put post-its on the organisational and industrial lock-in sources, somewhat neglecting the rest of the lock-in sources. However, as I will showcase in the following section, his inputs aligned well with the rest of the lock-in sources.

8.6 Sorting responses into the lock-in sources

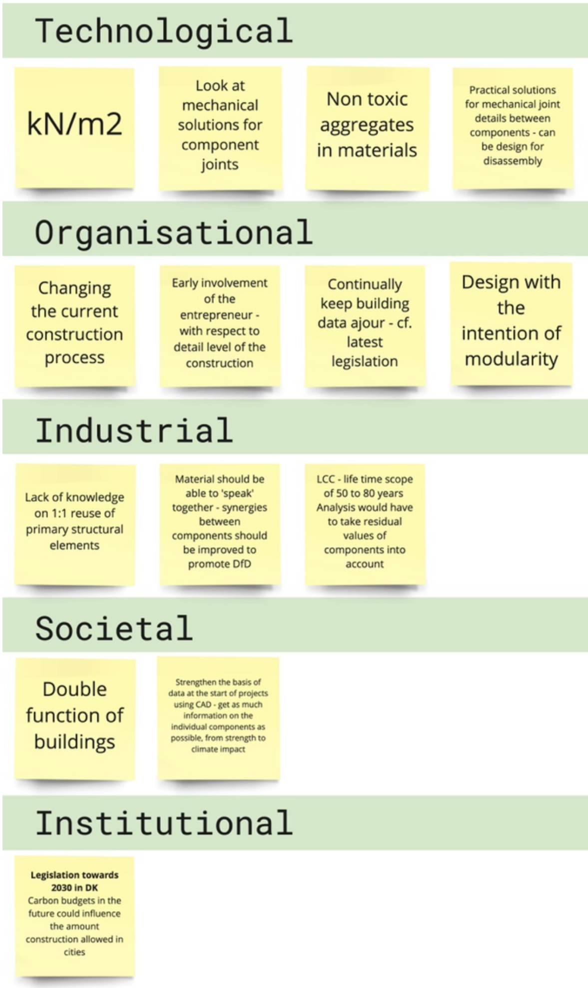


Figure 10: All answers sorted according to the lock-in sources

After the interview, I gathered the responses from all three parts and mapped them according to the five lock-in sources. It is quite clear that his profession is rooted in the construction and design phase of buildings, seeing as his responses and solutions fall under technological and organisational lock-in. Yet, he suggested initiatives which could address both societal and institutional lock-in, pointing to him recognising the need for a broader transition of sociotechnical networks to enable circular economy – e.g., suggesting changes to how we use buildings in general. Furthermore, the suggestions that corresponded with industrial lock-in issues aimed to promote greater transparency from industry stakeholders. Enabling greater knowledge sharing and accountability while also addressing how to enable feasible business models for circularity. Lastly, he emphasised that multiple upcoming legislative changes would influence how construction projects were planned, scoped, and carried out.

8.7 Caveats and thoughts

The design game was not meant to let me draw any solid conclusions; instead, it was aimed at helping me identify possible shortfalls in my analysis. Instead of adding valuable insights on how to enable the reuse of components, the design game added further validity to the suspicion that stakeholders in the construction industry are not ready to tackle the issues.

I have to caveat the findings with observations from the interview that might have influenced the answers and outcome. First and foremost, the participant came into the meeting unprepared, having only his professional expertise to fall back on. This could have led to his apparent focus on Ramboll initiatives – designing future buildings with circularity in mind. Furthermore, as I have only interviewed one person it would be premature to draw any decisive conclusions; it does, however, raise questions and hypotheses warranting further exploration. The implications of such further exploration will be handled in the discussion.

Additionally, the form of the design game coupled with the functionality of Miro might have hindered his ability to articulate possible futures. The observation stems from the fact that he did not attempt to draw any arrows even though I told him he was free to do so. Yet, that could also be due to a fault on my part, as it might not have been entirely clear what the objective was. An example could have helped outline what I wanted him to do, which I failed to demonstrate. During the game, I did mention that the objective was to get the new building built from demolition materials but failed to convey that I meant “a building that would be built today”, which could explain his focus on future initiatives rather than actions which could be implemented today.

Lastly, the visual expression of the design game could maybe have been more explicit in conveying the objective. If I only wanted to focus on how to enable the reuse of building components, then I should perhaps not have included the build and use phase. However, I suggest that leaving them out could have stifled the conversation, as he seemed to focus more on building design and planning. If I were to do the design game again, I would make the objective clearer. If that still does not help generate answers on how to reuse components today, I could confidently say that knowledge and practices related to reusing components today are lacking. As of now, it only lends more credibility to the notion of lacking focus and expertise without confirming or affirming the suspicion.

However, one of the main findings is related to his focus on building design. It suggests that Ramboll has not considered the consequences of demolition nearly as much as the design of buildings. Several factors could cause this prioritisation; one aspect could be that there are not sufficient business opportunities to support the work necessary to focus on the demolition phase. Furthermore, it could be due to Ramboll not considering building buildings from reused components as a feasible option. It could very well be that they are aware of the sector’s challenges while deciding that it would be too big of an issue to tackle. Although, Ramboll consulting a client on a resource mapping suggests that there are at least clients out there willing to confront the issues and find solutions. Questions will still pertain to Ramboll's role in the transition. I will relate the findings of the analysis of sociotechnical imaginaries and my suggestion for a possible future framing of demolition waste elements.

8.8 Implications for Ramboll's Sociotechnical Imaginary

Analysing the work SSC and Ramboll Buildings conduct to address the challenges related to transitioning to a circular economy. Having both the perspective of framing and overflow and sociotechnical imaginaries allows for analysis on a micro and macro level. Deploying framing and overflowing to contextualise the work related to specific materials – what knowledge is needed, which qualities need to be included in the reframing process, and which actors need to be included in the new frame. Situating the analysis at the micro-level. Using the knowledge acquired from Unruh (2002) to determine instances of lock-in Ramboll at the macro-level.

It seems evident that Ramboll is quite aware of the magnitude of the challenges related to transitioning to circular principles. Having at least two departments focusing on finding solutions that can accommodate circular economy principles. However, alignment between departments was lacking when it came to defining responses to issues related to the transition. This could point to a disagreement in the interpretation of circular economy between the two departments. Hinting at possible organisational lock-in at Ramboll, as they are not equipped to deal with the issues identified – reasons outlined in the findings from the design game.

Thus, the circular world they try to project through their sociotechnical imaginary is not internally aligned due to both different interpretations of circular economy and lack of managerial know-how in solving the challenges related to the implementation of circular economy. To confront the misalignment, Ramboll would have to know what keeps concrete waste materials from functioning in a circular capacity. In the next section, I will present a thorough examination of the framing of concrete waste materials.

8.9.0 Five sources of lock-in – five aspects of framing

Having established that reuse is the least studied and practised part of the 3Rs – identified as a fundamental strategy to circular economy. It is evident that the requalification and reframing need to be established with regard to enhancing the possibility of reuse. Several observations work to underpin the validity of the claim.

First and foremost, the sheer quantities of concrete used in the construction sector render circumventing the challenges created by its usage practically impossible. There is no feasible substitution for concrete at the time being, forcing stakeholders to consider how reuse practices can be introduced – especially considering the thresholds set by the EU Taxonomy. Secondly, the recycling of construction- and demolition waste is a well-established practice, albeit not in relation to new construction projects. Yet, the infrastructure and technical know-how are present to succeed with recycling, with encouragement from the EU Taxonomy and other legislative drivers aiding in adoption. Lastly, reuse practices do not benefit from the same *end-of-pipe* solutions as recycling (Unruh, 2002). Instead, *continuity* or even *discontinuity* political approaches are needed (Unruh, 2002).
A first step to help foster these changes is to identify and articulate areas that need to be requalified and reframed, allowing reusable materials to circulate on the market — making

it possible to establish viable business models around the reuse of demolition waste concrete. The design game yielded several different insights into the drivers of lock-in. Although they are not explicitly related to the reuse of concrete components, they still depict significant barriers to transitioning to a circular economy – see Figure 10.

Using the aspects identified in the design game as an out-set for further detailing of the barriers impairing the reuse of components. The following analysis is a consolidation of observational, empirical- and theoretical data, which help determine the new framing of demolition waste materials. Thus, viewing concrete waste materials through the lens of circular economy, denoting qualities that either align or misalign with the concept. In doing so, establishing an overview of which aspects would have to enter the new frame for the material and which should be left out.

The requalification will be done with respect to the lock-in sources identified in Unruh's (2002) theory of carbon lock-in (Unruh, 2002). The lock-in sources define which dimensions need to be considered in achieving a new framing (Callon, 1998). Furthermore, using Çalişkan & Callon's (2009, 2010) theory of Economization to ensure alignment with market ideas (Çalişkan & Callon, 2009, 2010).

Legend: "+" denotes an aspect that aligns with circular economy principles, and "÷" denotes an aspect that does not align with circular principles

<u>8.9.1 Technological lock-in</u>

To identify areas of requalification of the technological lock-in sources, it is first necessary to distinguish between the two most common ways of using concrete in the construction sector. Concrete is either pre-cast at a factory or cast on-site (in-situ casting). Both methods have their specific circumstances that have to be considered (*Precast Concrete vs Site Cast Concrete | Nitterhouse*, n.d.). An overview of the different aspects of the two methods will be provided in the tables below. They contain a classification of the different characteristics concerning their compatibility with circular economy principles as outlined previously.

Pre-cast		
+	Standard size	The standard size of pre-cast elements makes planning for reuse less difficult, as architects and building planners know the dimensions and quality of the concrete elements
+	Uniform quality	Elements produced at a factory is more uniform in quality, removing uncertainties in structural calculations using reusable components
÷	Requires more joints	The smaller size of pre-cast elements requires more joints to assemble, making disassembly harder
+	Locked-in system	The assembly system for pre-cast elements is more uniform – noticeably pre-cast elements from the same manufacturer. Easing knowledge production in relation to reusing the elements, as actors will encounter the same systems more often

+	Savings scales with project size	Seeing as careful demolition is a more expensive option than normal demolition, having a cheaper option when building could off-set some of the extra costs associated with careful demolition
+	Better potential	All in all, due to less cost and a more uniform system, the potential to build circular practices around pre-cast elements seem promising, as actors have an easier time planning around the use of said elements

In-situ casting		
±	Versatile / customisable	In-situ casting can solve challenges related to unique circumstances at each specific construction site. Making them more versatile in their deployment. Elements could solve issues elsewhere, but questions pertain to the feasibility of reusing custom elements
÷	Cannot be standardised	The versatility comes with a price seeing as the concrete is cast on-site, weather conditions and air composition influence the curing of the cement. Making each element unique, furthermore the custom shapes does not lend itself well to standardisation
+	Less joints	The bigger size of in-situ casting benefits disassembly, as they require fewer joints. Making it easier to source whole elements
÷	Unique shapes	The unique shapes are unlikely to be useful elsewhere
+	Cheaper on smaller projects	Smaller projects benefit from on-site casting, in terms of savings. Could potentially off-set some of the cost associated with disassembly and transport of the bigger pieces

Both		
÷	No material passports	Both processes suffer from a lack of material passports. Material passports are not widely implemented, thus under ordinary circumstances neither in-situ casting nor pre-cast have material passports, however both could support the concept
÷	Not designed for disassembly	Seeing as design for disassembly is not the default practice, both suffer from being difficult to disassemble. However, both could support the practice, with pre-cast being the

		best suited to facilitate reuse

8.9.2 Organisational lock-in

When considering circular economy, technical aspects are central to achieving circularity, e.g., knowing how to process and (re)use a given material. However, the organisation of stakeholders to facilitate the circulation of materials is just as important. Organisational lock-in hampers abilities that will aid in transitioning to a circular economy.

Organisational lock-in		
÷	Linear supply chain	The complexity and linearity of the supply chain present disadvantages for the implementation of circular principles. The supply chain is geared toward benefitting the current practices; hence it has a hard time accommodating a circular supply chain (Benachio et al., 2020; Eberhardt et al., 2019; Hossain et al., 2020)
÷	Lack of coordination between construction phase and *end-of-life* phase	Buildings are not designed with its *end-of-life* phase in mind, making demolition and reuse more difficult than it has to be. Furthermore, tools like BIM and *cradle-to-cradle* LCA accounting are not a common practice (Akanbi et al., 2018; Ghisellini et al., 2018; Kanters, 2020; Pomponi & Moncaster, 2017)
÷	Difficult to justify ROI	With an increase in demolition costs if careful demolition practices were to be introduced, it is difficult to assess whether a suitable business model could be established (Miljøstyrelsen, 2018)
÷	Industry set-up	The construction industry with all its legislation, permits, insurance, and bureaucracy is not designed to support circular principles (Eberhardt et al., 2019; Kanters, 2020)

8.9.3 Industrial lock-in

The industrial aspects of the construction sector are by no means irrelevant; they are, however, to some degree, black-boxed in this thesis. Seeing as the current industry supplies the demand set by the construction sector, changes to building practices will lead to changes in demand from the construction sector. Implementing circular economy principles will undoubtedly influence how the construction material industry operates since less material will be needed while new materials could possibly enter the construction sector. Nonetheless, some industrial lock-in sources still influence the requalification of concrete waste materials.

Industrial lock-in		
÷	Building standards does not allow for reuse	Questions pertain to reusing components as there is still a 'grey area' around the legislation and insurance. Studies show that components can be reused, but legislation

		outlining the rules of such practices still needs to be ratified (Eberhardt et al., 2019; Kanters, 2020)
÷	Marketing and lobbyism from material manufacturers	The construction industry has powerful stakeholders that aim to further their interests. Companies such as Aalborg Portland, Rockwool etc. continually work to make sure that their products are seen as favourable by legislation. Which, if circular economy were to come to fruition potentially would not be the case

8.9.4 Societal lock-in

Thinking of societal lock-in requires considering the social preferences we have attained through our collective conjunction with the current TIC. Hence, expectations of specific outcomes and processes are at the core of the lock-in source. As a society, we have come to expect particular mechanisms that we take for granted; these mechanisms can hinder the adoption of circular principles.

Societal lock-in		
÷	System socialisation keeps practices consistent	The construction sector is geared toward delivering buildings in a certain way. One which does not lend itself well to circular principles. The way financing, procurement, and permits are obtained are all working against making the industry more circular
÷	Expectations of buildings being in a certain way	New buildings are often designed by architects to be unique and exciting in some way or another. Which requires custom elements and considerations. Having to reuse components can potentially limit the artistic freedom of architects and designers. Potentially leading to backlash from customers commissioning buildings.
÷	Stakeholders occupy predetermined roles in construction projects	The way the construction sector is organised works against the implementation of circular economy. The different phases a building must go through when it is being built, combined with the shifting agency between stakeholders along the construction phases hamper circular economy adoption.

8.9.5 Institutional lock-in

The legislation that governs the construction sector plays a vital role in shaping the industry. Laws can enable and hinder a transition, creating lock-in through policies promoting a particular agenda. Circular economy is gaining attention from lawmakers in Denmark and the EU, introducing policies with an increasing focus on circular economy. These policies either help to upkeep existing TICs or dismantle them.

Institutional lock-in		
+	The EU Taxonomy push for reuse	With the EU taxonomy becoming effective sooner rather than later, it will act as a main driver for the adoption of circular principles. Asserting influence on stakeholders in the industry such as entrepreneurs, building companies, project administrators, and financial institutions
÷	Waste sorting legislation might be counter productive	Waste management legislation states that 70% of construction and demolition waste should be sorted at the source, which could lead to components being broken down into its individual constituent parts. Possibly destroying reusable components in the process in an attempt to reach the goals set by the legislation. The EU is aware of this issue and has made it clear that the legislation is aiming at promoting selective demolition (*Construction and Demolition Waste*, n.d.)
÷	Building permits do not allow for design for disassembly	Obtaining a building permit when building a building designed for disassembly could be difficult, as building codes are focused on energy performance requirements (Kanters, 2020)
+	Increasing focus on circular economy from legislators	Circular economy is gaining popularity throughout the World, with the EU, UK, and China all having implemented legislation aimed at promoting circular economy. With Canada and Japan well on their way with their own versions of a taxonomy, institutions all over the world are recognising the need for change (*A European Green Deal | European Commission*, n.d.; *Circular Economy Promotion Law of the People's Republic of China. | UNEP Law and Environment Assistance Platform*, n.d.; *Sustainable Taxonomy Development Worldwide: A Standard-Setting Race between Competing Jurisdictions | Our Center of Expertise*, n.d.)

These tables together with the findings from the design game present a unified theory of what the new framing should include. Being assembled from insights from a sectorial expert, empirical- and theoretical data, it presents a broad overview of what is needed to promote reuse of concrete waste. Although not an exhaustive list, it encompasses and addresses the main problematisations identified. Allowing me to deploy the lock-in framework presented to assess what should remain in the frame and what should be negotiated.

8.10 The New Frame for Demolition Waste Materials to Encourage Reuse

As was evident from the design game, together with the known issues related to demolition, the first step towards a new frame is shifting the focus from the design and build phase of buildings to the demolition phase. The new framings need to frame careful demolition and reuse of components as favourable to sourcing new materials. By utilising the insights above, it becomes possible to articulate which qualities of concrete waste work against the new framing and which suits the new framing.

In the illustration below (Figure 11), it can be seen which aspects influence the current framing and which aspects need to be introduced to establish a new frame. I have chosen to illustrate the contrast between the two framings as an old-fashioned scale. There are several reasons for this choice; firstly, market participants value the current framing higher than the proposed framing. Evidenced by the notion mentioned earlier:

> *"In short, things circulate because they are valued and it is because they are valued that they become goods"* (Çalişkan & Callon, 2009, p. 389)

The waste moves in the patterns it does because that is how stakeholders value it. Secondly, the evidence is backed up by the behaviour of stakeholders such as Ramboll, that, contrary to their intentions, does not seem to fully accommodate the circular principle of reusing, seeing as their focus seems to be on the design and planning phase.

In clearly illustrating the 'old' framing and the new framing, I hope to convey the difference between the two framings as clearly as possible. Hopefully, allowing them to negotiate each aspect on the scale and determine how to configure an aspect to allow it to move from the weight bowl representing the old framing and over onto the weight bowl representing the new framing.

For stakeholders such as SSC, it further helps them articulate their sociotechnical imaginary, as they now have a thorough description of each aspect and visual representation of those same aspects, which should help them to identify relevant stakeholders and avenues of improvement.

In the following section, I will discuss the implications of the findings from both the analysis and the design game in relation to my problem formulation.

8.11 The Weighting Between the Linear Acceleration Economy and Circular Economy

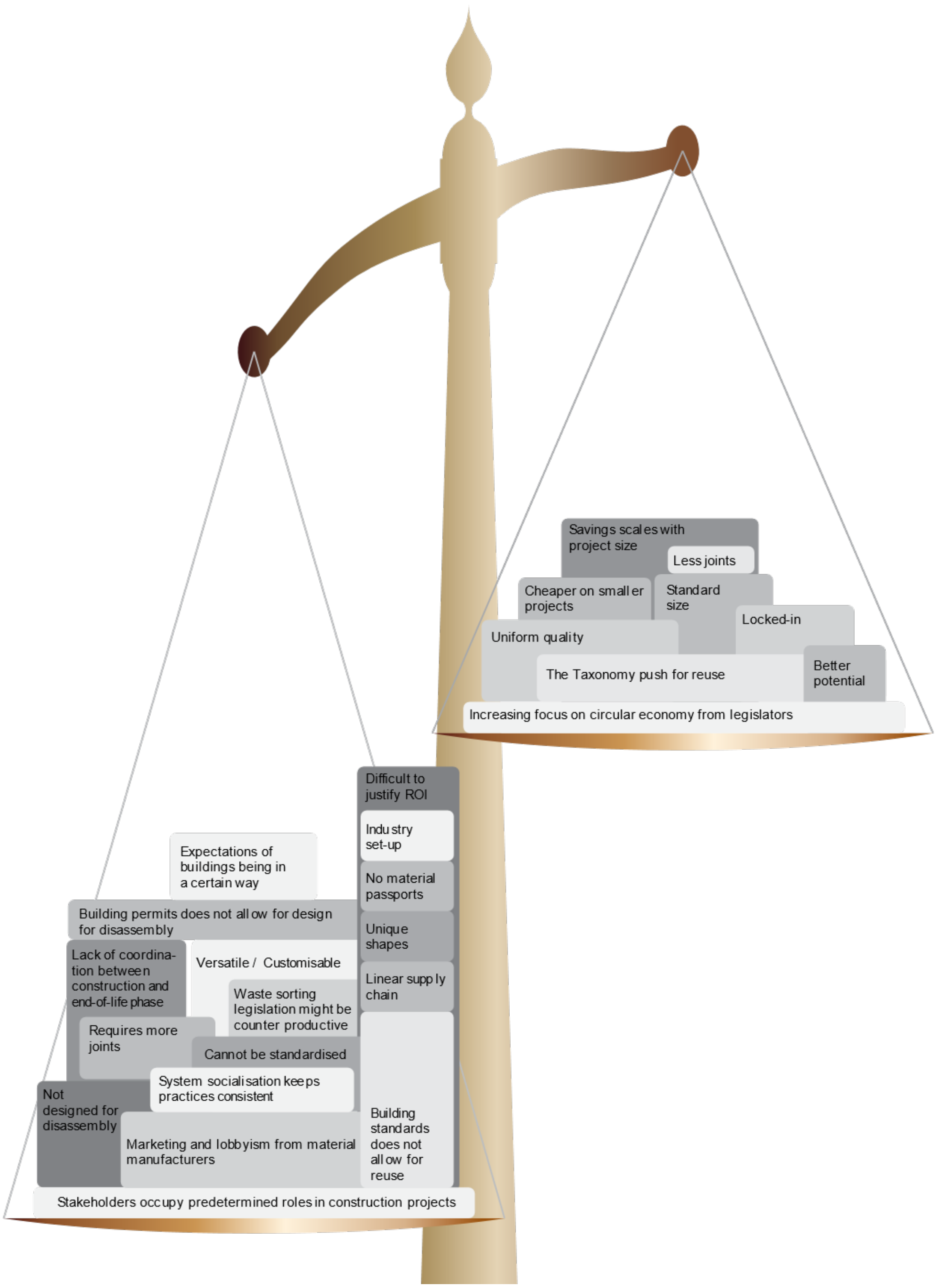
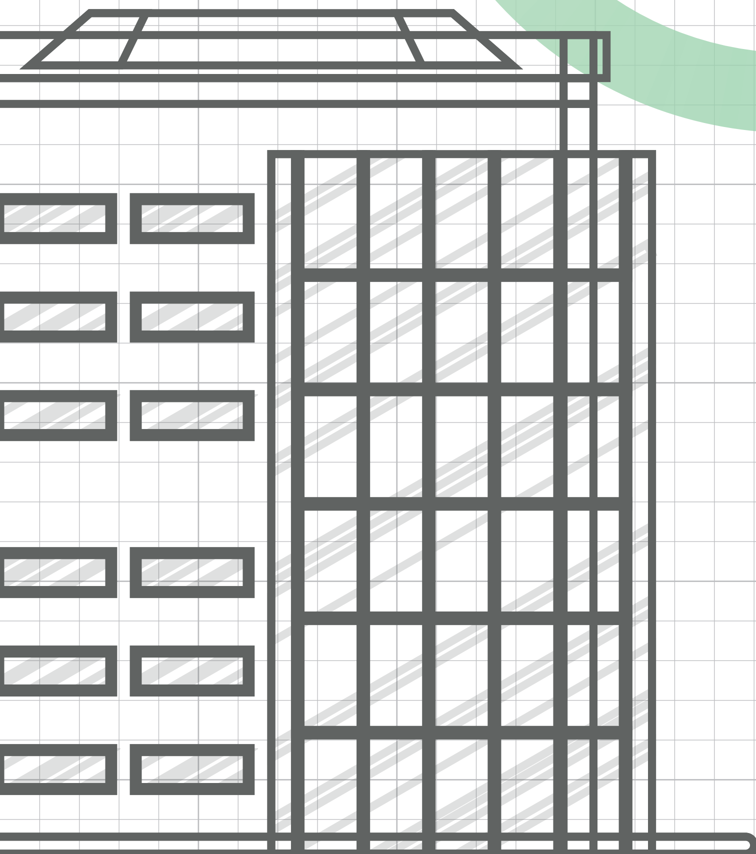


Figure 11: The weight of the aspects favouring linear resource consumption is preferred over the aspects of circular economy

Part 5
Discussion & Conclusion



9.0 Discussion

This thesis took an outset in the problem of shifting from linear material consumption to circular reuse of building materials and informed the problem formulation:

How does the requalification of demolition waste material affect the possibility of transitioning construction companies towards using 15% reused, 15% recycled, and 20% renewable construction material in accordance with the forthcoming EU Taxonomy?

This section aims to discuss the findings of this thesis; I first want to discuss the implications of the two framings of building materials presented above. Subsequently, I will discuss how the design game could be used to further expand data gathering and exploration of the suggested framing. Lastly, the findings complicate how I view my problem formulation; the reasons for this observation will be discussed.

9.1 Discussion of the Implications for Stakeholders

The scale illustration I have introduced clarifies that the existing qualifications of concrete waste materials make them more suitable for flowing in the linear acceleration economy than re-circulating in a circular economy. In my attempt to illustrate the prioritisation of qualities in the two competing framings, some nuance is lost. Thus I find it necessary to reiterate the complexity of the issue. The multitude of different dimensions nested in the framings cannot be seen from the illustration. As I have showcased, not only is the transition to the reuse of concrete waste material deeply rooted in technical aspects, but also the associated societal, legislative, and organisational aspects of the TIC need consideration too. Accepting the premise of the transition being reliant on all five aspects of lock-in also means that the burden of work to transition increases quite considerably (Unruh, 2002).

I have illustrated, the broadening of the understanding of the drivers and barriers to the implementation of circular economy also points to a misalignment between the normative concept of circular economy and how to implement it and the 'real-world' implementation of circular principles. By following specific materials, I have demonstrated that the common 'solutions' to address circular economy in the construction industry are insufficient – or at least not encompassing all the challenges facing the sector. Examples of this count both scholars and companies such as Ramboll emphasising that new business models are needed without recognising the underlying issues that the analytical work of this thesis has uncovered.

My study shows how reuse of specific materials could be facilitated. The discrepancies between the ideal vision TIC of circular economy and the requirements for actual implementation of a circular economy TIC have been identified. The strategies and solutions set by the ideal vision TIC of circular economy are severely limited in its practical applicability. To say that reuse should be implemented in construction projects is reductionist at best and ignorant at worst. The over-simplification of the ideal strategies could have implications for the sociotechnical imaginary of the EU and SSC.

The EU Taxonomy is made to categorise and measure economic activities concerning sustainability. With the Taxonomy being one of the main tools the EU have at their disposal to monitor and quantify sustainable development, it lies at the heart of their Green Deal sociotechnical imaginary. Yet, the EU taxonomy is a first step in moving in the new direction. Still, it may risk ending up 'involuntarily' black-boxing reuse, seeing as the EU Taxonomy fail to elaborate the technical screening criteria for reuse. This observation also further validates my claims of a misalignment between the ideal vision of the TIC for circular economy and what it really would entail creating a successful TIC for circular economy.

Despite the EU's best efforts in defining the 'playing field', they fail to establish clear 'rules' or 'intentions' for reuse. Letting it be up to the stakeholders involved in construction activities to figure out how to best find a solution. The approach could yield favourable results if not for the latent barriers tied up in the lock-in sources. Thus, stakeholders trying to establish viable business models are at a disadvantage as all factors standing in the way of reuse are not known.

The diffuse understanding of circular economy presents challenges for SSC as well. Seeing as they are attempting to form a service offering that can accommodate clients working in the construction sector. If SSC develop their service offering based on reuse being exclusively a technical challenge, they risk falling short in their endeavour. Even though SSC realise that the task is complex and requires multiple different elements to succeed, I suspect they are unaware of how difficult it is to reuse concrete building components in the current linear economy.

SSC needs to use their leverage within the Ramboll organisation to create a more cohesive sociotechnical imaginary, to be able to address the challenge more effectively. A sociotechnical imaginary where Ramboll works with all the aspects of lock-in, as I have outlined in section 7.5, they act in a similar capacity to policymakers. They have the possibility of acting as a facilitator of negotiations between stakeholders, allowing them to address most of the lock-in sources directly – the societal lock-in is quite challenging to address directly as it relates to the expectations and norms of society, something that comes to be and changes over time. I still concede that by being thought leaders and spearheading truly circular initiatives, they could be the catalyst for this change in societal lock-in.

9.2 Discussion of the Implications for the Problem Formulation

The findings of the analysis have influenced how I view the problem formulation in terms of the difficulty related to requalification of concrete waste materials. The problem formulation is written as follows:

How does the requalification of demolition waste material affect the possibility of transitioning construction companies towards using 15% reused, 15% recycled, and 20% renewable construction material in accordance with the forthcoming EU Taxonomy?

Going into this thesis, I was influenced by the same ideas of the ideal version of circular economy, thinking it was mainly a technical issue. I thought that knowing the concrete waste material better would allow it to circulate in a circular economy. Yet, not only are there issues related to the materiality of concrete – its heavy usage, assembling techniques that make it hard to disassemble once cast, and the fact that other materials get mixed into the concrete elements. There are other categories of issues not directly related to concrete extending out in multiple dimensions. Making the requalifying process of concrete waste material a challenging and extensive task, certainly way more extensive than first envisioned. The problem formulation and its conclusion will be presented in the conclusion.

9.3 Discussion of Further Work

I find it relevant to discuss potential avenues for further work in conjunction with the findings. Seeing as I only interviewed one person, and as I discussed earlier, it would be interesting to host additional interviews where the design game is utilised. Albeit, the design game would have to be equipped with the knowledge obtained in both this study and from the first use of the design game. Making the design game an iterative tool where new knowledge continuously can be equipped makes it possible to further detail the aspects of requalification – especially in relation to organisational lock-in, as interviewees' answer will aid in understanding the way their respective organisations work.

Secondly, it gives an opportunity to confirm or deny some of the suspicions that I have articulated from the design game results. Despite the interview being very informative, the answer was still only from a single person's point of view, which definitely could skew the picture in any which way. More interviews remove the ambiguity surrounding some of the problem areas – such as Ramboll's heavy focus on building design and planning.

Lastly, the lock-in framework which has been presented makes it possible to negotiate possible futures of what can remain in the framing and what should be removed. Hopefully, allowing for a more concise discussion of how to enable the reuse of concrete waste materials.

10.0 Conclusion

This thesis set out to determine whether a requalification of demolition waste material is a viable strategy in enabling the transition towards meeting the requirements set by the EU Taxonomy.

I first want to address the possibility of re-qualifying demolition waste materials. Using Callon's (1998) re-qualification theory in conjunction with Unruh's (2002) theory of TICs in an analytical capacity have allowed me to look past the apparent technical nature of the problem. In doing so, identifying the specific conditions that perpetrate the misalignment between the ideal vision TIC of circular economy and the specific 'real world' TIC. Taking TICs into the consideration in the re-qualifying process also lets me contemplate how re-qualifying concrete waste materials affect the possibility of transitioning construction companies.

As I have shown in the literary review, recycling practices for demolition waste materials are well-established. Despite the black-boxing of recycling practices, I still argue that it requires relatively minor tweaks to accomplish the 15 per cent threshold, compared to reuse. Considering the usage of renewable construction materials, as the same practices and lock-in sources do not bind them, I expect it to be the least difficult threshold to accomplish. Reasons for this include; (i) As companies such as Ramboll are mainly focused on designing new circular buildings; they will increasingly start to incorporate renewable materials into their designs – as it is a central part of the ideal vision of circular economy, they seem to subscribe to (ii) Renewable materials are easy to plan around, seeing as they are not tied up in already built buildings, and can be included in ordinary procurement flows.
Contrarily, a major re-qualification of demolition waste materials is needed to accommodate reuse. I have demonstrated the broad extent of re-qualifying demolition waste materials using the lock-in sources, leading me to believe that it would, indeed, help with reaching the threshold. Accomplishing the re-qualification and new framing of demolition waste materials is another question altogether, which certainly would require further wide-ranging research to determine the feasibility of.

I believe that the EU Taxonomy will drive stakeholders within the construction industry toward attempting to reuse. Yet, the lack of consideration for the TIC and the accompanying lock-in sources would most likely lead to stakeholders failing to establish a standard reuse practice. Furthermore, I have demonstrated that specific issues hinder at-scale adoption of reuse practices. Bill of Materials not being readily available prohibits planning with reuse in mind, and the hard to disassemble building practices of past further exacerbate the issues. It seems evident that attempting to form policies around disrupting business-as-usual as little as possible would not suffice. Thus, I argue that continuity approaches to policy initiatives are at least needed. In some instances, discontinuity policy responses would be necessary to address some of the challenges facing the sector.

Thus, the sociotechnical imaginary of the EU is at risk of failing if the EU does not succeed in accommodating the different factors of lock-in, in doing so, addressing the misalignment between the ideal vision TIC of circular economy and the actual 'real world' TIC. This shift in focus should encompass moving away from focusing on design and planning out new buildings to focusing on demolishing buildings to harvest reuse components for new buildings.

10.1 Contribution to the Field of Sustainable Design Engineering

My contribution to sustainable design engineering lies on the level of sociotechnical systems (Ceschin & Gaziulusoy, 2019). Being a contribution towards the field of design for sustainability transitions. This claim is based on the framework that I have designed that allows designers to approach and address Techno-Institutional Complexes with an outset in the theories of re-qualification (Callon, 1998).

The contribution to the field of sustainable design engineering lies in part in expanding the usage of the theory of requalification from focusing on specific materials to focusing on TIC's. Without the approach, it is easy to get caught up in individual materials and legislation.

Acknowledging the TIC as a designable object allows for consideration of a much broader field. Adding to the field of design for sustainability transitions by recognising that concepts such as circular economy need to be locked-in the same way unsustainable systems are locked-in. Considering sustainability transitions through the lens of re-qualification and lock-in affords a greater level of detail in determining areas of action than any of the two theories would on their own.

This thesis also provides an overview of specific design questions that I argue were not clarified before. The subject area of circular economy in construction is rather diffuse; using the lock-in sources allows designers to focus on specific issues and materials.

11.0 References

7 Rebslagervej - Google Maps. (n.d.). Retrieved May 6, 2022, from https://www.google.dk/maps/@55.7025972,12.5365489,3a,75y,320.66h,98.1t/data=!3m6!1e1!3m4!1soIgnb9YugQmVtGaM_OuEVA!2e0!7i16384!8i8192

A European Green Deal | European Commission. (n.d.). Retrieved May 14, 2022, from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#thebenefitsoftheeuropeangreendeal

About Cement & Concrete : GCCA. (n.d.). Retrieved April 5, 2022, from https://gccassociation.org/our-story-cement-and-concrete/

Akanbi, L. A., Oyedele, L. O., Akinade, O. O., Ajayi, A. O., Davila Delgado, M., Bilal, M., & Bello, S. A. (2018). Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator. *Resources, Conservation and Recycling*, *129*, 175–186. https://doi.org/10.1016/j.resconrec.2017.10.026

Arora, M., Raspall, F., Cheah, L., & Silva, A. (2019). Residential building material stocks and component-level circularity: The case of Singapore. *Journal of Cleaner Production*, *216*, 239–248. https://doi.org/10.1016/j.jclepro.2019.01.199

Arora, M., Raspall, F., Cheah, L., & Silva, A. (2020). Buildings and the circular economy: Estimating urban mining, recovery and reuse potential of building components. *Resources, Conservation and Recycling*, *154*. https://doi.org/10.1016/j.resconrec.2019.104581

Benachio, G. L. F., Freitas, M. do C. D., & Tavares, S. F. (2020). Circular economy in the construction industry: A systematic literature review. In *Journal of Cleaner Production* (Vol. 260). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.121046

Birgisdóttir, H., & Madsen, S. S. (2017). *Bygningers indlejrede energi og miljøpåvirkninger. Vurderet for hele bygningens livscyklus* (J. Kirkeskov, Ed.; 1st ed.). Polyteknisk Boghandel og Forlag ApS.

Brandt, E., Messeter, J., & Binder, T. (2008). Formatting design dialogues - games and participation. *CoDesign*, *4*(1), 51–64. https://doi.org/10.1080/15710880801905724

Buildings and construction. (n.d.). Retrieved May 31, 2022, from https://ec.europa.eu/growth/industry/sustainability/buildings-and-construction_en

Çalişkan, K., & Callon, M. (2009). Economization, part 1: Shifting attention from the economy towards processes of economization. *Economy and Society*, *38*(3), 369–398. https://doi.org/10.1080/03085140903020580

Çalişkan, K., & Callon, M. (2010). Economization, part 2: A research programme for the study of markets. *Economy and Society*, *39*(1), 1–32. https://doi.org/10.1080/03085140903424519

Callon, M. (1998). An essay on framing and overflowing: economic externalities revisited by sociology. *On Markets*, 1–18.

Casper, M. J., & Latour, B. (2006). Pandora's Hope: Essays on the Reality of Science Studies. *Contemporary Sociology*. https://doi.org/10.2307/2655272

Ceschin, F., & Gaziulusoy, İ. (2019). *Design for Sustainability*. Routledge. https://doi.org/10.4324/9780429456510

Circle Economy. (2022). *The Circularity Gap Report 2022*.

Circular economy action plan. (n.d.). Retrieved May 25, 2022, from https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

Circular Economy Promotion Law of the People's Republic of China. | UNEP Law and Environment Assistance Platform. (n.d.). Retrieved May 18, 2022, from https://leap.unep.org/countries/cn/national-legislation/circular-economy-promotion-law-peoples-republic-china

Construction and demolition waste. (n.d.). Retrieved May 18, 2022, from https://ec.europa.eu/environment/topics/waste-and-recycling/construction-and-demolition-waste_en

Eberhardt, L. C. M., Birgisdottir, H., & Birkved, M. (2019). Potential of Circular Economy in Sustainable Buildings. *IOP Conference Series: Materials Science and Engineering*, *471*, 092051. https://doi.org/10.1088/1757-899X/471/9/092051

EU taxonomy for sustainable activities | European Commission. (n.d.). Retrieved May 3, 2022, from https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en

EUROPA - Competition - List of NACE codes. (n.d.). Retrieved May 3, 2022, from https://ec.europa.eu/competition/mergers/cases/index/nace_all.html

FIEC Statistical Report. (n.d.). Retrieved May 31, 2022, from https://fiec-statistical-report.eu/

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. In *Research Policy* (Vol. 31).

Ghisellini, P., Ripa, M., & Ulgiati, S. (2018). Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *Journal of Cleaner Production*, *178*, 618–643. https://doi.org/10.1016/j.jclepro.2017.11.207

Hossain, M. U., Ng, S. T., Antwi-Afari, P., & Amor, B. (2020). Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. In *Renewable and Sustainable Energy Reviews* (Vol. 130). Elsevier Ltd. https://doi.org/10.1016/j.rser.2020.109948

Jasanoff, S., & Kim, S.-H. (2009). Containing the Atom: Sociotechnical Imaginaries and Nuclear Power in the United States and South Korea. *Minerva*, *47*(2), 119–146. https://doi.org/10.1007/s11024-009-9124-4

Kanters, J. (2020). Circular building design: An analysis of barriers and drivers for a circular building sector. *Buildings*, *10*(4). https://doi.org/10.3390/BUILDINGS10040077

Karnøe, P., Iuel-Stissing, J., & Georg, S. (2019). *From bio-mess to legitimate biomass and back to bio-mess: The epistemic work and controversies of making and un-making an energy resource*.

Miljøstyrelsen. (2018). *Ressourcekortlægning af bygninger*. Miljøstyrelsen.

Nuñez-Cacho, P., Górecki, J., Molina-Moreno, V., & Corpas-Iglesias, F. A. (2018). What gets measured, gets done: Development of a Circular Economy measurement scale for building industry. *Sustainability (Switzerland)*, *10*(7). https://doi.org/10.3390/su10072340

Oberle, B., Bringezu, S., Hatfield Dodds, S., Hellwig, S., Schandl, H., Clement, J., & United Nations Environment Programme. (2019). *Global resources outlook 2019 natural resources for the future we want*.

OECD. (2018). *OECD HIGHLIGHTS Global Material Resource Outlook to 2060 -Economic Drivers andEnvironmental Consequences*.

PLATFORM ON SUSTAINABLE FINANCE: TECHNICAL WORKING GROUP. (2022). *PART B – Annex: Technical Screening Criteria*.

Pomponi, F., & Moncaster, A. (2017). Circular economy for the built environment: A research framework. *Journal of Cleaner Production*, *143*, 710–718. https://doi.org/10.1016/j.jclepro.2016.12.055

Precast Concrete vs Site Cast Concrete | Nitterhouse. (n.d.). Retrieved May 12, 2022, from https://nitterhouseconcrete.com/precast-concrete-vs-site-cast-concrete/

Rosa, H. (2013). *Social Acceleration - A New Theory of Modernity* (J. Trejo-Mathys, Ed.; 1st ed.). Columbia University Press.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis and Strategic Management*, *20*(5), 537–554. https://doi.org/10.1080/09537320802292651

Stephan, A., & Athanassiadis, A. (2018). Towards a more circular construction sector: Estimating and spatialising current and future non-structural material replacement flows to maintain urban building stocks. *Resources, Conservation and Recycling*, *129*, 248–262. https://doi.org/10.1016/j.resconrec.2017.09.022

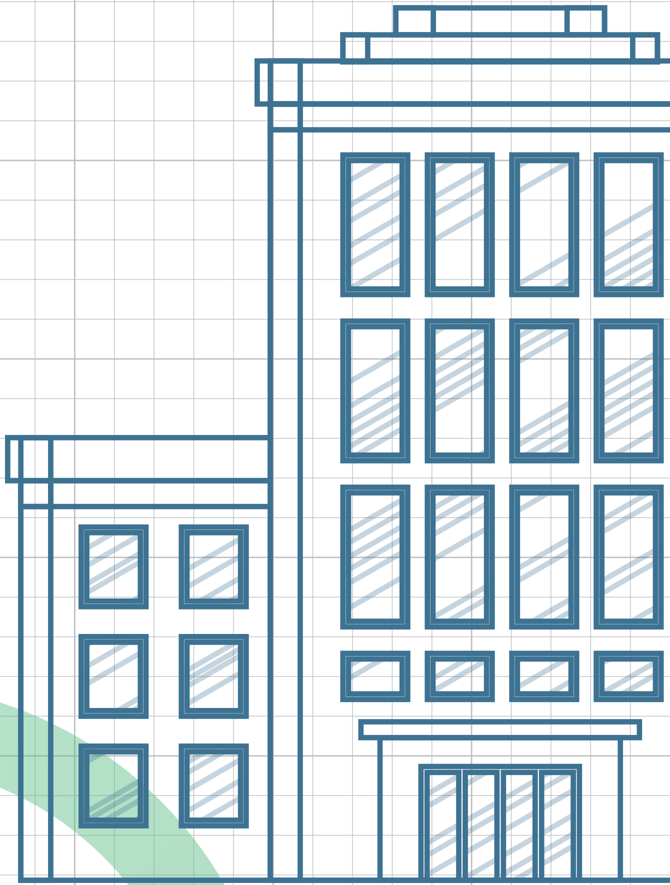
Sustainable Taxonomy development worldwide: a standard-setting race between competing jurisdictions | Our Center of Expertise. (n.d.). Retrieved May 18, 2022, from https://gsh.cib.natixis.com/our-center-of-expertise/articles/sustainable-taxonomy-development-worldwide-a-standard-setting-race-between-competing-jurisdictions

Unruh, G. C. (2002). Escaping carbon lock-in. *Energy Policy*, *30*(4), 317–325.

Vaajakallio, K., & Tuuli, M. (2014). *Design games in codesign: as a tool, a mindset and a structure*. *10*, 63–77.

What is a circular economy? | Ellen MacArthur Foundation. (n.d.). Retrieved June 1, 2022, from https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

World Population Growth - Our World in Data. (n.d.). Retrieved April 5, 2022, from https://ourworldindata.org/world-population-growth



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