A collaboration tool for circular innovation settings.

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Abstract

The socio-technical approach to addressing sustainable transition is useful for contextualizing the lock-ins of existing linear technical, institutional and behavioral dimensions. This socio-technical, systemic approach of addressing sustainable transition is useful for contextualizing complex societal problems and identifying the technical, institutional and behavioral dimensions that lock-in building industry norms.

This Sustainable Design Engineering master's thesis aims to apply this systemic perspective to analyze the opportunities for and barriers to implementing Circular Economy (CE) in the Danish building industry. What this study highlights is that a majority of academic literature, case-study and demonstration projects are characterized by a technocratic focus and seek to make visible the sustainability potentials of CE building principles. While these analytical investigations are an important part of CE implementation, they overlook the complexity of the social and behavioral conditions of the cross-disciplinary, inter-organizational change processes needed to implement circular innovations.

While sustainable transition literature recognizes the social and behavioral dimensions as mutually reinforcing the technical and institutional, very little attention is given to understanding these highly relational conditions. Therefore, this master's thesis integrates key insights from organizational theory and innovation studies with the aim of identify social and behavioral conditions conducive to collaborative innovation settings for higher order learning. As a conclusion to this study, the design is presented of collaboration tool for circular innovation settings. This boundary object was designed with the aim to facilitate dialogue and communication between actors, establish goals and visions for circular project ends, facilitate the boundary work essential to fostering new behaviors, and to document new knowledge generated throughout reflexive processes. This tool is useful for buiding industry project managers, circular consultants and resource coordinators working to implement circular innovations in transformation projects.

Glossary

Circular Economy
(CE) will be used in this document to describe circularity and "circular thinking." throughout the document.

Building Industry
Throughout this document the term "building industry" is meant to encompass the many professional practices which contribute towards the creation of buildings.

Lendager
Lendager Group is the main collaborative partner of this study and will be referred to as Lendager throughout this document.

CIRCUIT
CIRCUIT is the "EU Horizon 2020 – CIRCUIT "Circular construction in regenerative cities" project.

Actors
All building industry experts who participated in this study will be referred to as "actors" throughout.

Transformation
Transformation is the blanket term chosen for the practices of renovating, retro-fitting and general re-use of buildings.

Preface

This thesis project is the culmination of four semesters of study at Aalborg University in the Sustainable Design, MSc Engineering program. I entered into this program with the desire to help push the Danish building industry towards a sustainable transition. In my education and career as an architect, I often felt ill-equip to navigate the wicked problem associated with tackling climate change, in a profession that was a major contributor to the problem. Hoping to be a part of the solution, I enrolled.

Since moving to Denmark in 2014 Circular Economy (CE) has been a topic of interest, debate, and curiosity. As an architect many of the CE design principles put forth as solutions seemed plausible to me, and certainly more sustainable than linear alternatives, but I still wasn't sure if CE was "the answer". Furthermore, my point of view was limited to that of the architectural profession and the promise of CE seemed to be on a more systemic level. I needed to know more, hear from other professions, and study the problem from a broad angle. I have used this education and this thesis as an opportunity to dive into this curiosity: "Can circular economy facilitate sustainable transition within the building industry?" While this is the question that started this endeavour, I know now it is too early to determine such a thing. In any case, this study has provided me with a lot of insight that I hope is also useful in the readers' own sustainable journey. Without further ado…

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CONTENT

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ABOUT THIS STUDY

About this study

1.1 A context for exploring CE

This study was conducted in collaboration with Lendager. Lendager is considered a circular frontrunner in the building industry. Lendager's practical insight into the intersecting filed of CE and the building industry is unmatched by other building industry professionals and has proven to be an integral contribution of this thesis. Lendager is a cross-disciplinary organization founded on the principles of CE in which three distinct departments work together to contribute towards sustainable transition of the building industry through architectural design, material innovation and circular consultancy. Lendager has proven through many demonstration projects that CE has potential to be an enabler of sustainable transition in the building industry.

In order to understand and address the challenges associated with Lendager's mission to "Design the world of tomorrow with the waste of today. While working towards designing a world without waste" (Lendager & Vind, 2018, p.58) this thesis began with the research question: *"What are the opportunities for and the barriers towards implementing circular economy in the Danish building industry?*

In order to best answer this question and examine the current state of CE implementation in the Danish building industry it was important to go outside the context of Lendager's organization and speak to a broad range of actors working to implement CE in the building industry. To do so, this thesis is conducted through the lens of a large multi-partner, cross-sector transition project: EU Horizon 2020 – CIRCUIT "Circular construction in regenerative cities" of which Lendager is a participating member. CIRCUIT and its Danish network of actors are the setting for empirical data generated in this study, of which specifics will be elaborated on in Chapter 5.

1.2 Sustainable transition in the building industry

It is calculated that the building industry accounts for 100 billion tons of waste, of which only 8.6% is cycled back into the economy (Circle Economy, 2021). Buildings are primarily built of materials with high embodied energy and are the responsible for the consumption of 33% of the steel, 20% of the plastics, 25% of the aluminium, and 65% of the cement used in the EU (Valeche-Altinel et al., 2021). Due to this consumption, the building industry is a major contributor to carbon emissions, climate change, virgin material extraction, pollution and waste disposal consuming roughly 40% of all material globally and generating 35% of the worlds waste, of which most ends up in landfills or incineration plants. Of the world's waste only 5-10% is generated by the construction of new buildings, whereas the rest comes from renovation and demolition processes (GXN Innovation, 2019). It is estimated that between 20-30% of building materials are recycled or reused at the end-of-life of a building (Leising et al., 2018). These statistics present a picture of a wasteful take-make-throwaway society. Where there is such epic resource failure, there is also massive opportunity to innovate.

World population is expected to double by 2030, resulting in a housing demand for over 4 billion people. As a consequence of this growth, the global building industry will need to generate 40 times more building stock than built in the last 4,000 years combined (Eberhardt et al., 2019). In order to capture the immense opportunity and material potential within our existing building stock, we must re-frame building waste as valuable material resource and create building industry practices around this knowledge (Ellen MacArthur

Foundation [EMF], 2013; Jørgensen & Remmen, 2018; Valeche-Altinel et al., 2021).

Transitioning away from the current linear production methods is critical towards staying within planetary boundaries and avoiding Earth's tipping points (Hill-Hansen, 2021). We must move beyond inadequate, sustainable development paradigms that frame social, economic, and environmental sustainability as separate pillars and move towards an integrative, transformational approach in which human development is reconnected with the biosphere, meeting the unprecedented environmental crisis of our time. In order to arrive in this "safe and just space" (Raworth, 2018), we must move towards a de-carbonized society in the coming 30 years, in which an economy of cyclical material flows will minimize virgin material use, reducing human impact on Earth's natural systems (Hölscher et al, 2018; Richardson, 2019; Rockström, 2015; Sachs et al., 2019). In addition to such strategic shifts there must be a "mind shift toward universal values that reconnect world development with a resilient Earth, recognizing the right of all to development" (Rockström, 2015, p.10) while promoting a shift away from materialistic lifestyles to a pursuit of well-being.

1.3 Defining a research inquiry

The Circular Economy (CE) concept has potential to be such a driver towards sustainable transition but lacks distinct demonstration projects, prescriptive methods, and process tools required to support such technical, institutional and behavioral change in the building industry (Korhonen et al., 2018). CE innovation processes demand new ways of collaborating, co-creating, and generating new knowledge in inter-organizational, cross-disciplinary settings. Therefore, project organization, and change management are crucial to the successful implementation of CE at the building scale. Existing literature on CE in the building industry (case-studies, academic articles and industry reports) have a tendency to embrace a high technical and analytical approach to documenting CE. Such studies are useful in making visible the sustainability potentials for circular building principles but do not illicit or make visible the learning outcomes of the processes that garner such results. Meaning, there is a knowledge gap around the innovation processes being conducted in niche, circular building projects. Therefore, studies such as this thesis which situate niche, circular innovation processes within the context of sustainable transition studies are in need (Hill-Hansen, 2021). At the same time, the co-evolving technical, institutional, and behavioral socio-technical lock-ins (Unruh 2000, 2002) create persistent barriers to implementation of CE as mainstream building industry practice.

This study finds that there is consensus among building industry actors regarding technical barriers and infrastructural needs (such as better digitization of material banks and physical storage of such materials) and need for institutional changes (such as building codes, tendering processes and educational reform). The literature identifies a need to create prescriptive methods for the creation of new, circular value chains or rather networks of building industry actor, yet very little of the socio-technical studies seek to understand the social and behavioral dimensions of transition projects. This study underlines the importance of behavior and social, process related, people-to-people changes in which there is a need for new ways of working together, creating and sharing knowledge in circular innovation settings, based on a new mind-set and value system.

There is a need for actors who can facilitate such collaborative processes. For these reasons, there is a need for studies which investigate the process related, qualitative, collaboration tools to facilitate in the adoption of circular building principles by mainstream actors and help coordination across the value chain.

Based on these demands this thesis seeks to answer the following questions:

"What new methods of collaboration are necessary in circular building projects?" and
"What kind of tool is needed to facilitate such a collaborative interaction?"

These questions are addressed by taking a sustainable transition studies approach to understand sustainable development within the Danish building industry. This approach is complimented by integrating insights from organizational and innovation studies. The motivation for doing so is that on-going circular demonstration projects are highly dependent on the quality of interaction between collaborative partners. Meaning, that while little emphasis has been placed on the behavioral and social conditions that define circular innovation projects, the outcomes are highly dependent on the creation of conditions conducive successful collaboration. As such, new methods of collaboration are needed that work to create new behaviors around the circular problem solving contexts. The process by which this study was conducted is illustrated in **Figure 1** and will be elaborated on in the following subsection.

1.4 A reading guide

The process by which this thesis was conducted (**Figure 1**) and the way in which this report is structured do not follow identical paths– therefore this introductory chapter is concluding with a description of the report structure. The core of the report is in this main document, however an appendix is attached with supporting documents, such as process work. This document is written using both chapters, sections and subsections. All illustrations included in this report were drawn by the author, unless stated otherwise.

The report structure is conceived of in two parts. In the first part Chapter 2-4 all the general information is presented, where is in the second half Chapter 5-8 is content specific to this thesis. First the theoretical framework used to structure and make sense of this study is articulated in Chapter 2. The methods used to support this approach through the generation and documentation of empirical data are presented in the Chapter 3. A review of literature already written on the subject of CE in the building industry is presented in Chapter 5. The context in which this report is situated is detailed in Chapter 5. Chapter 6 and Chapter 7 present and make sense of empirical data generated in this study. After which the solution, or rather "design space" is presented in Chapter 8. Finally, Chapters 9-10 wrap-up the study with discussion and conclusion.

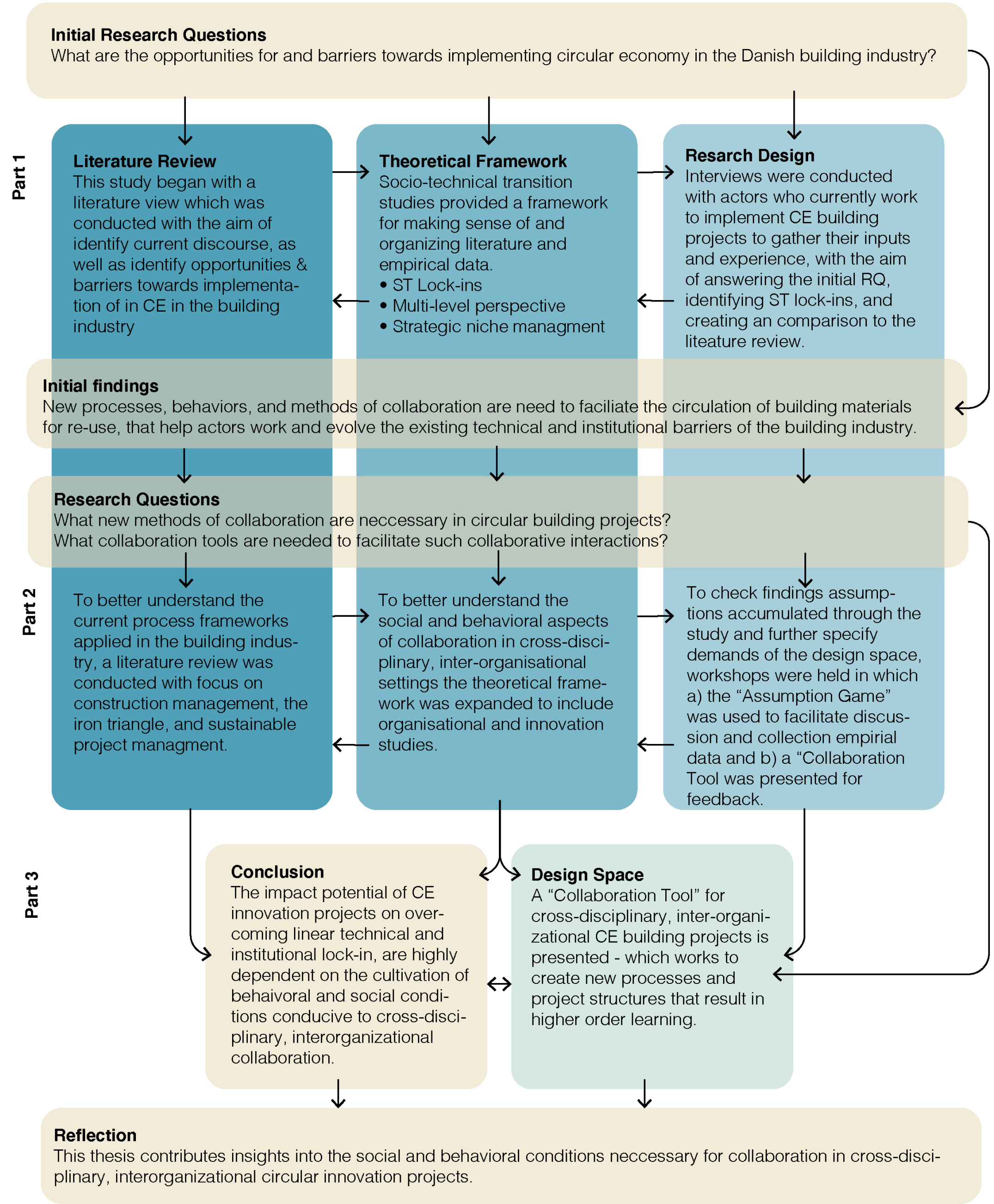


Figure 1
Process Diagram

2

A THEORETICAL FRAMEWORK

2 Theoretical Framework

1.1 A context for exploring CE

In order for CE to develop in the building industry a systematic approach must be taken to transforming the current linear approach to doing things to reflect circular principles. Such a transformation of the development path will impact the *technical*, *institutional* and *behavioral* that define the building industry as we know it today. Transition studies offer an analytical framework that is useful to both describe and make sense of what is currently going on. Such an analytical framework can also be used to describe a desirable future in which sustainable transition leads to the adoption of circular building principles.

Theoretical frameworks have been applied in three ways during this study, therefore, the theoretical framework is written in three parts. In Chapter 2.1 key insights from sustainable transition studies are used to analyze the existing conditions of the building industry and identify barriers to and opportunities for creating new sustainable transition pathways. This section of the report is used as an theoretical framework for analyzing empirical data presented in Chapter 6.1. As the researcher moved from problem definition to design space it was necessary to rely on theoretical frameworks that sit outside of socio-technical studies to better understand the behavioral and social context of collaboration. Such theoretical frameworks include organizational studies and innovation studies and are presented in Chapter 2.2 and are used as a theoretical framework to analyze empirical data presented in Chapter 6.2. Finally, the theoretical concept of *boundary objects* (Star, 2010) is explored in Chapter 2.3 and will be applied in the Design Space - Chapter 8.

2.1 Sustainable transition studies

As mentioned in Chapter 1, sustainable transition of the building industry is of key importance to meeting climate targets in Denmark, and beyond. Governance has either an enabling or discouraging role to play in transitioning society for long-term sustainable development: “Actors use rules to interpret the world, make sense and come to decisions. Rules are not just constraining (making some actions more legitimate than others), but also enabling (creating convergence of actions, predictability, trust and reliability” (Geels & Schot, 2007, p.403). Sustainable transition studies often encourage *reflexive governance* in which transition management is designed “For short-term innovation and develop long-term sustainability vision linked to desired societal transition” (Loorbach, 2010, p.163) where a focus is placed on developing the capacity to mobilize, guide, and accelerate social innovation at a pace rapid enough to meet the *wicked problems* of our times.

Rittel and Webber (1973) defined *wicked problems* as complex social or cultural problems that are so ill-defined (lacking clarity in both aims and solutions) it is nearly impossible to solve them and wrote that “the process of solving the problem is identical with the process of understanding its nature” (p. 162) meaning there is no direct way of telling when the problem has been solved.

Our society is growingly complex and is the origin of deep rooted, persistent, long-term problems. Society has potential to create innovations needed to deal with such problems. Despite writing about the transformational nature of sustainable transition projects, the literature does not really consider the processes (social and behavior acts) by which transformations come to be. Contrasting the slowness of change in the construction sector, is the knowledge that the window of opportunity to transition towards sustainable practices is relatively short, and rapidly approaching (Röckstrom, 2015; Sachs et al., 2019) . The scale and depth of *wicked problems*

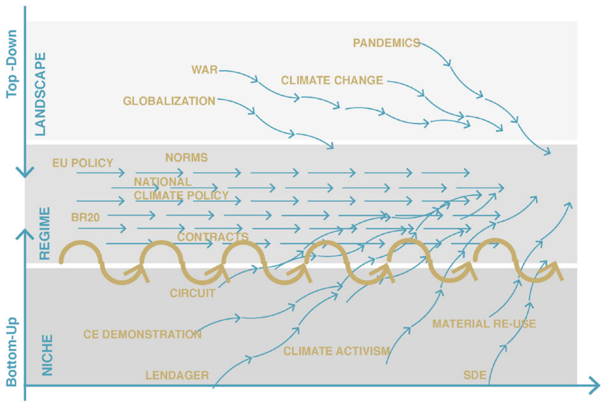


Figure 2
MLP framework with relevant examples from this thesis

wdemand rapid innovation across design scales. Given the unwieldy nature of socio-technical systems, the rate at which innovations must diffuse and be adapted by mainstream regime actors is unlikely unless all three types of the socio-technical lock-in (technical, institutional, and behavioral) co-evolve together. (Brown & Vergragt, 2008).

In order to facilitate sustainable transition, governance models should prioritize "learning, interaction, integration and experimentation on the level of society" (Loorbach, 2010, p.164) in which systems thinking is central and innovations are conceived from an understanding of the complex networks which they are a part. Innovation projects for sustainable transition must be understood as the "multi-level, multi-phase processes of structural change in societal systems" (p. 167) in which interaction patterns (social and behavioral) between individuals, organisations, and networks lead to the stability of regimes overtime.

To understand the complexity of multi-level, multi-phase approaches it's useful to apply Multi-Level Perspective (MLP) which describes a framework for understanding our society in three systematic levels: the Niche level, the Regime level, and the Landscape level, as pictured in **Figure 2**. Niches can be understood as small-scale endeavours, such as the CE pilot projects, that seek to challenge business-as-usual. Regimes are socially accepted and recognized as norms, such as building codes and construction contract structures. Regimes are stabilized by laws, practices, and networks that constantly reproduce their function, and determine their path of development. Furthermore regimes are solidified through the way market mechanisms work. Finally, the Landscape is defined by historically prominent, defining moments such as world wars, global pandemic, and climate change (Geels, 2002; Geels & Schot, 2007; Seto et al., 2016).

2.1.1 Strategic Niche Management (SNM)

The SNM approach suggests that through the creation of technological niches, or *protected spaces* (Smith & Raven, 2012) technology is experimented with and co-evolved with user practices (behavior) and regulatory structures (institutions), such as circular demonstration projects. Niches can be a place for "mutual articulation (and alignment) of technology, demand and broaden societal issues" such as sustainable development or circular transformation (Schot & Geels, 2008, p. 539) and provide a protected space where a specific set of challenges are addressed by their representative actor groups, in a controlled setting. Within protected, niche innovation spaces technologies are shielded, nurtured and empowered in a setting where they are exposed to the selection pressures of the regime in a highly controlled context (Smith et al., 2005; Smith & Raven, 2012).

Historically, SNM has built on the premise that through the careful creation of niches, large societal shifts towards sustainability are possible. SNM suggests that niches are the place for internal steering or nudging, through specific learning processes, demonstration projects, or collective enactment (Schot & Geels, 2008). SNM was developed to serve innovation projects which are socially desirable with long-term goals such as sustainable transition, radical novelties which don't fit within the existing technological, institutional and behavioral lock-ins of the regime. SNM suggests management of innovation projects should happen internally where decisions are made by actors involved. SNM suggests key strategies for successful implementation of niche innovations can be summarized as a) the articulation of expectations and visions for direction of learning goals and legitimization of the project and b) building of strong, social inter-organizational networks including relevant outsider to broaden cognitive frames and commitment to implementation of innovation. These facets, among others, lead "higher-order learning" (Brown & Vergragt, 2008) which ensures niche innovation projects lead to transition pathways (Schot & Geels, 2008).

Schot & Geels (2008) suggest that the process of learning, networking, and visioning is integral in bringing niches into the technological regime. The authors articulate the mutually dependent relationship between micro local niche practices (short-term) and macro global regimes (long-term). Meaning, while actors innovate at the niche level, they must be aware of and understand development of external regime processes and factors, such as socio-technical lock-ins (Unruh 2000, 2002).

Niche innovation projects won't transform the regime through bottom-up changes alone, but rather through coordinated alignments of processes at both the regime and landscape level. MLP emphasizes that change takes place through a process of co-evolution and mutual adaptation by regime actors within and between the layers: "the dynamic is less about substitution and more about how niches may branch, pile up, and contribute to changes in the behavior, practices and routes of existing regime actors" (Schot & Geels, 2008, p. 548). Niches should work to create coalitions of key actors, who are situated in influential positions within the regime. Positioning of such actors contributes to the niches ability to withstand selection pressures of the regime level and improves adaptive capacity (Smith et al., 2005).

2.1.2 Inertia of the regime

To best understand the path-dependencies that define regime level we can look to Unruh's (2000; 2002) concept of socio-technical *lock-in* which is categorized by the *technological*, *institutional* and b*ehavioral lock-ins* **Figure 3**. In Unruh's original definition of lock-in, he was referring specifically to the dynamics of carbon lock-in of energy systems. This study takes a departure from that original idea and uses the concept of lock-in in several ways. First, the lock-ins categories are used to identify and organize barriers to and the opportunities for implementation of circular economy in the building industry in the mapping of empirical data, as described in Chapter 3 – Methods. Secondly, the concept to lock-ins is applied to better understand how to reconfigure or rather unlock the linear construction processes that dominate the building industry today and is used to organize and make sense of the empirical data presented in Chapter 6.1 and 6.2

Technological lock-ins relates not just to individual technological innovations, but also the enabling and supporting infrastructures and consists of dominant designs as well standard technological architectures and their compatible components. As such, technological lock-in is reflected in industry standards and competencies that have developed over long periods of time.

Institutional lock-in relates to industry and inter-industry forces of coordination such as, creation of standards, networks of private associations, educational institutions, policy and regulatory bodies which "create non-market forces of lock-in through coalition building, voluntary association, and emergence of society norms and customs" (Unruh, 2000, p.823) Such aspects are reflected in organizational settings through routines, trainings, and departmentalization.

Behavioral lock-in relates to habits, cognitive routines, lifestyles, expectations and preferences. Such behavioral aspects are created through two types of socialization: through individual decision making and social structure (Unruh, 2000, 2002; Geels, & Schot, 2007; Seto et al., 2016).

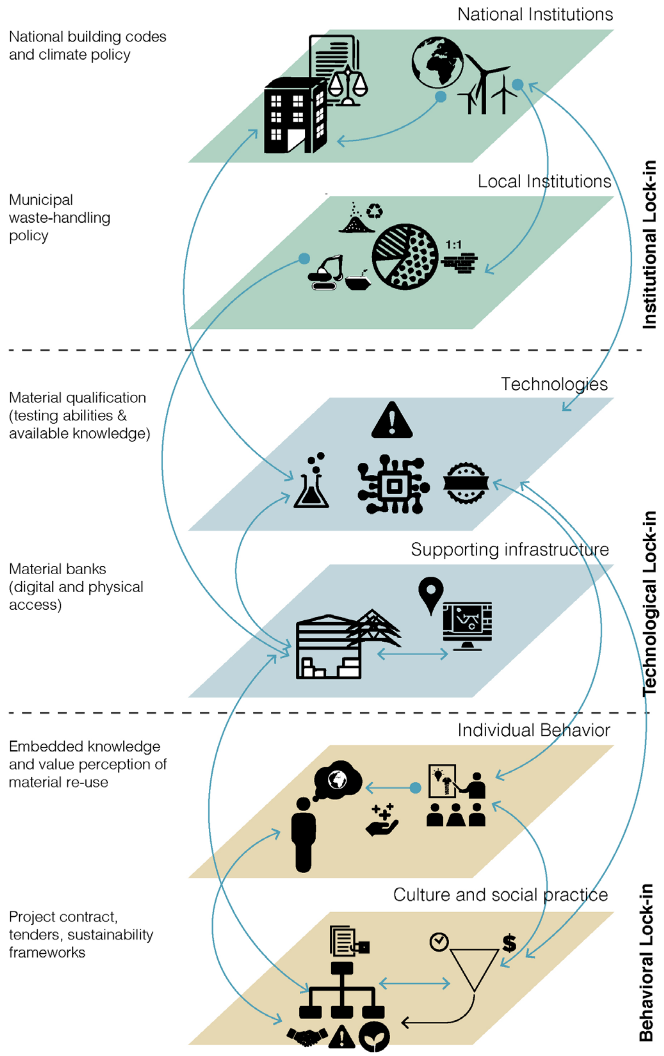


Figure 3
Mutually re-enforced lock-ins. (Inspire by Seto et al., 2016)

The process of learning, networking, and visioning is integral in bringing niches into the technological regime

Collaboration is relational, subject to social and psychological processes.

Lock-ins are: "mutually reinforcing and create collective inertia - meaning attempts to change one type of lock-in results in "hardening or compensating resistance to change" (Seto et al., 2006, p.427). This techno-institutional complex (TIC) (Unruh, 2000) creates persistent incentive structures that influence both a systems stability and ability to evolve, or rather path-dependency. Lock-ins are most visible in the technologies used, institutions supported, and behaviors of regime actors. The effect of institutional and behavioral lock-ins on the building industry is most visible when studying traditional construction management frameworks.

The literature presented above devotes a lot of attention to the structural conditions for the technical and institutional development of sustainable systems. Although behavioral aspects of norms, habits and routines are mentioned, much less attention is given to the factors change these things, such as the forming of networks and cross-disciplinary, inter-organizational collaboration. To better understand these behavioral conditions this study navigates outside of sustainable transition literature in the following sections.

2.2 Collaboration in cross-disciplinary, inter-organizational contexts

In this section of the Theoretical Framework the goal is to make sense of the *behavioral lock-ins* of the building, industry to better understand the way organisations work together in cross-disciplinary, inter-organizational contexts and understand what conditions are conducive for successful collaboration. Furthermore, this section examines which conditions maximize "higher order learning" and knowledge creation for new behaviors and processes around circular building project.

2.2.1 Collaboration is relational

Developing CE in the building industry has many of the characteristics of *wicked problems* (Rittel & Webber, 1973). CE as an avenue for sustainable transition is currently ill-defined. There is no agreed upon problem or solution and the complexity of unlocking linear construction practices is both social and cultural in nature. In order to address such complexities building industry actors are going to have to work together in new ways. CE innovation projects demand cross-disciplinary, interorganizational collaboration which often involves a wide-range of actors, whom each have their own interest, perspectives, identities, varying in size and power dynamics. In such a setting "complexities are of strategic, informational, procedural, yet also of a relational nature as in the end collaboration is a social activity" (Schruijer, 2020, p.1). Even the most successful of collaborations deal with painfully slow processes associated with "learning by doing." Inter-organizational collaborations are faced with both social and psychological processes and their respective emotional roots, that occur throughout the process, such as: trust and distrust, group stereotyping and conflict, inclusion and exclusion of stakeholders, power struggles and leadership dynamics to name a few. Collaboration "simultaneous invokes conscious and unconscious emotional, relational, political processes that pose various challenges to the social system" (Schruijer, 2020, p.3). In general, collaborations tend to follow an organizational development process in which a) relationships are built, b) identities and interdependencies are explored, c) trust is developed and d) a self-governed collaborative environment is mutually articulated. Through such a process, roles are defined and validated as the collaborating group arrives at a share vision or goal. It is therefore necessary to better understand the relational dynamics of collaborations to find strategic ways to intervene for the better (Schruijer, 2020). Such relational dynamics are explored through *boundary work* (Bos-de Vos et al., 2019).

Pioneering boundary work is needed in circular cross-disciplinary, inter-organizational innovations settings to establish new role structures among actors outside of the scope of their traditional professional practice.

Absorptive capacity and resource fitness are pre-conditions for successful collaborations.

2.2.2 Defining collaboration roles through boundary work

Due to rigid institutional lock-in, the construction industry has a highly embedded and established role structure. Role structures help support the development of inter-organizational, cross-disciplinary construction projects and counterbalance the uncertainty that comes with an ever-changing constellation or consortium of actors formed around each building project. The temporality of such a context means actor roles are (re) negotiated through "sayings and doings of actors"or as Bos-de Vos et al. (2019) defines as *boundary work* as either *reinstating*, *bending*, or *creating pioneering roles* in which actors work to shape new roles for themselves in construction projects. In the context of CE building projects, the *bending* and *pioneering* practices of boundary work are most common, in which actors must apply their *embedded knowledge* (Carlile, 2002) to create both new methods, processes, and collaboration structures across the project value chain. *Reinstating* boundary work refers to when actors feel their contribution and expertise is undervalued and they must prove their worth, often resulting in a need to emphasize or justify their role. *Bending* boundary work refers to when actors see an opportunity to offer additional services beyond, and act more fluidly within the context of a project, while remaining strongly linked to traditional scope of tasks. *Pioneering* boundary work refers to actors feel that they must change the rules of the game transforming the field with adopting a new role in the consortium and radically changing project structures. With pioneering boundary work alternative collaboration structures are created which work to "redefine the role of the actors in a given project to improve collaboration and contribute to transforming the field" (Bos-de Vos et al., 2019, p.149). In the changing landscape of circular building projects, roles become less demarcated and more fluid, meaning "Professionals do not only need to work across boundaries to integrate different domains of expertise and practice, they also need to cope with the changing boundaries that define their work" (Bos-de Vos et al., 2019, p.131).

2.2.3 Collaboration for value creation

Value created (new knowledge), value proposition (knowledge contributed), and value capture (knowledge acquired) in innovation projects should benefit all actors involved. Furthermore, establishing shared values and aligning goals are key mechanisms by which committed relationship between actors are established (Leising et al., 2018). Collaborators should actively participate in key decision making, idea generation, and goal setting to ensure that all actors know how to and when to interact with each other (Lang et al., 2012). In the construction industry, much of these elements are decided in the contract and bidding phases. Thus, it is of key importance to have all actors participate early in the process (Bos-de Vos et al., 2019; Cheng et al., 2008; Leising et al., 2018).

When actors contribute to decision making and decided on the distribution of responsibility (control and power) they are given agency over the project: "all parties involved have jointly held knowledge and information, thus requiring effective interorganizational knowledge sharing" (Cheng et al., 2008, p.285) reducing uncertainties and increasing trust. Trust leads to strong network dynamics in which new networks are created around a) actors, b) resources (fiscal, time, know-how) and c) activities to combine, create or exchange new resources (both material and information flows). All of which exchanges are essential to creating new circular economy value chains (CEVC) (Leising et al., 2018).

To facilitate inter-organizational knowledge transfer, actors must demonstrate adequate *absorptive capacity* which is understood as the ability to assimilate and apply new knowledge in a way that benefits the commercial

For maximum value creation and transition potential collaborations should focus on creating conditions for higher order learning.

goals of an innovation project or an organization (Cheng et al., 2008; Gluch et al., 2020). Furthermore, *resource fitness* is considered a considered prerequisites for knowledge diffusion between collaborators and is defined as an actor's ability to "share its explicit and tactic knowledge with its partners" (Cheng et al., 2008) as well demonstrate a commitment to face-to-face interaction. When actors have excellent absorptive capacity and resource fitness, inter-organizational trust intensifies, as does willingness to share sensitive information often critical to the innovation process (Cheng et al., 2008; Gluch et al., 2020; Lang et al., 2012). Furthermore, actors are more likely to participate in problem solving in disciplines around a particular set of problems (pioneering boundary work), rather than in siloed organizations– which is quite necessary in innovation projects. Gluch (2020) writes "to stimulate collaboration there is a need for effective social integration mechanisms to facilitate information exchange" (p.373) between actor groups. Such mechanism can be referred to as *boundary objects* (Star, 1989) and will be expanded on in subsequent sections.

2.2.4 Knowledge creation for "higher order learning" in collaborative settings

In order to meet the demand for innovations across system scales there is a need for knowledge creation and *higher order learning* around circular building practices, in which building industry professionals and their respective communities of practice (individuals, organisations, and networks). must establish new norms, practices, and problem definition in a coordinated effort with institutional changes (such as policy, building codes, and financial incentives). Brown & Vergragt (2008) define *higher order learning* as "a radical change in interpreting observations and in solving problems and advancing objective" (p.110). *Higher order learning* is also referred to as "second order", "double loop" or "generative learning" in organizational science and entails the changing of "assumptions, norms, and interpretive frames which govern decision-making process" (Brown & Vergragt, 2008) p.111).

Higher order learning is said to take place though reflexive processes in which self-evaluation is an essential feature. Through a process of learning, solutions, once considered normative are no longer fit the bill in modern scenarios and a sense of urgency forces trial-by-fire, iterative learning processes. Higher order learning happens when actors establish new multi-disciplinary ways of problem solving and broaden the scope of their collective responsibilities through *boundary work* (Bos-de Vos et al., 2019; Leising et al., 2018). As underlined in Chapter 2.1 by Schot and Geels (2008) "Futuring" or collective visualization and scenario building is recognized in organizational science as a key aspect of higher order learning (Brown & Vergragt, 2008). "Visions do not only provide an image of possible future, but also provide coordination among heterogeneous actor groups, and guidance and orientation for join action towards that future" (Leising et al., 2018, p.997). According to Wegner (2000) a key aspect of the learning process is a feedback process by way of interaction between "the deep competency possessed by a community of practice and the experience it acquires by interacting with the outside world" (Brown & Vergragt, 2008, p.111).

Through boundary processes or boundary work knowledge is produced. Such work is enhanced by collaborative innovation projects which work to solve a specific problem, ability to create and communicate in a common language, and the presence of actors who serve as communicators of new ideas *knowledge brokers* (Kimble et al, 2010) within their respective community of practice. As such, Brown & Vergragt (2008) argue that in successful Bounded Socio-Technical Experiments

New interpretive frames are needed for actors to bring circular behaviors outside of the innovation context.

Sustainable transition projects should reflect on learning processes for better practical understanding of how to implement CE innovations.

Collaboration tools should communicate localized, embedded, and invested knowledge between actors.

(BTSE) or what is referred to in SNM as niches (Schot & Geels, 2008; Smith et al., 2005; Smith & Raven, 2012) that the process of higher order learning can result in "functioning, socially embedded new configurations of technology or service" (p.113) and can serve as a starting point for diffusion at the regime level.

"Well established professional assumptions and norms of behavior can strongly influence one's interpretive frame. Interpretive frames resist change, but can do so, especially in crisis situations" (Brown & Vergragt, 2008, p.115) which we find ourselves in today. The building industry is in need of new values, behaviors, and *interpretative frames*. Niche innovation projects, which stem from a vision for a circular building industry have potential to create change of in actor behavior, so long as higher order learning is achieved. "Considering the profound importance of small-scale experiments in producing major shifts in socio-technical regimes, a detailed analysis of learning processes is important for better theoretical and practical understanding of such shifts, and for developing the right conditions to facilitate them" (Brown & Vergragt, 2008, p.127).

2.3 Boundary objects to facilitate creation of knowledge and enhance higher order learning

As underlined in the preceding section of this chapter, the creation of knowledge through higher order learning is essential to successful development of sustainable innovation projects. Tools, models, diagrams, or objects which facilitate in the visualization and documentation of such knowledge are needed to organize project structure and create common ground between collaborating partners.

The concept of *boundary objects* (Star, 2010) is introduced in this section and will be applied in the context of the Design Space – Chapter 8. Star defined *boundary objects* as: "objects that are shared and shareable across different problem solving, contexts" (Carlile, 2002, p.451) and are described as "the stuff of action" (Star, 2010, p.603) residing between social worlds or communities of practice, mediating across *knowledge barriers* (Carlile, 2002; Star & Greisemer, 1998). *Boundary* refers to both the edge and also a shared space, while *Objects* are considered material things that people act towards or with (Star, 2010) such as tools, models and diagrams (Hill-Hansen, 2021) - all of which can be understood "as a means of representing, learning about, and transforming knowledge to resolve the consequences that exist at a given boundary" (Carlile, 2002, p. 442).

Boundary objects can be used to communicate knowledge that is a) *localized* in character around a particular set of problems such as a material innovation project; b) *embedded* such as accumulative knowledge that is hard to specify or document because it is acquired through experience and; c) *invested in practice*, for example when proven successful, individuals are less likely to adapt their knowledge to accommodate those they collaborate with, and are dependent on in a problem-solving context. (Carlile, 2002; Hill-Hansen, 2021). Some collaboration processes require knowledge to be brokered by humans. Such actors use their central and influential role in the project to manage relations between collaborators, while also acting as translators of knowledge between collaborators. Such actors are considered knowledge brokers and often play an integral role in innovation processes (Kimble et al, 2010; Hill-Hansen, 2021). In the context of circular building industry project, the *knowledge broker* is often identified as a project manager or consultant.

Carlile (2002) defines three types of knowledge boundaries as *Syntactic*, *Semantic*, and *Pragmatic* **Figure**

The collaboration tool should work to develop a common language between collaborators and help them resolve their differences and dependencies.

4. The *Syntactic* approach establishes a shared syntax or common language for individuals to represent their knowledge, whether it is localized, embedded or invested in practice. Developing a common language is key in the context of cross-disciplinary, inter-organizational settings. The *Semantic* approach provides a concrete means for individuals to specify and pinpoint the differences and dependencies that exist across boundaries and recognizes that while a common syntax may be present – interpretations are often different depending on the different communities of practice present at that given boundary. The semantic approach is key to translating knowledge between actors, articulating visions, and setting common goals. The *Pragmatic* approach facilitates a process where individuals can jointly transform their at-stake, knowledge and "assumes the conditions of difference, dependence, and novelty are all present, and so recognizes the requirement of an overall process for transforming existing knowledge to deal with the negative consequences that are" (Carlile, 2020, p.444) thus creating new knowledge and validating that new knowledge between collaborators (Carlile, 2002). The Pragmatic approach is essential to facilitating collaboration processes that result in *higher order learning*.

All three knowledge boundaries are integral to transferring knowledge between building industry practitioners and should be considered when designing a boundary object for collaboration. This idea will be elaborated on in the Design Space – Chapter 8.

Types of Knowledge Boundary	Categories of Boundary Objects	Characteristics of Boundary Objects
• Syntactic	Repositories	Representing
• Semantic	Standardized forms and methods	Representing and Learning
• Pragmatic	Objects, Models, and Maps	Representing, Learning, and Transforming

Figure 4
Types of Knowledge Boundary, Category & Characteristics of Boundary Objects (Carlile, 2002)

3

RESEARCH DESIGN METHODOLOGY

3 Research Design Methodology

3.1 Grounded theory approach

This thesis was completed using the grounded theory approach following "The logic of discovery…it moves from the field to the desk and back, step-by-step, refining the emerging theory" (Czarniawska, 2014, p.24). First a site was chosen to frame the study, both spatially and temporally, of which specifics are detailed in Chapter 5 – CIRCUIT. Once a site was chosen the collection of accessible material of all kinds on the subject matter were collected. The materials collected in this thesis include academic articles, white papers, industry reports, newspaper articles, as well as internal documents produced by some of the interview subjects. This study was also subject to on-going public debates (via LinkedIn, industry online media) and industry conferences held during the research period.

Consistent with grounded theory approach, through the collection of information, a constant comparative analysis was conducted for emerging themes, which informed the direction of the research throughout the study. The empirical data generated in this study is a reflective of interactions between the author and the interviewees, meaning the author had an active role in shaping the outcome of this study. Furthermore, the process of data generation was informed by the Theoretical Framework – Chapter 2 chosen, which directed a vision for this thesis study and influenced extraction of empirical data. The details of methods used to generate data in this study are presented in 3.1, followed by a description of methods used to document and make sense of such empirical data in 3.2. The methods used to conduct the literature review are in section 3.3.

3.1.1 The interview approach

As part of this study the 14 building industry actors were interviewed who represent different roles within the building value chain (Architects, engineers, demolish companies, contractors, city planners, municipal developers, private developers, scientific researchers, material passport developers, legislative bodies, sustainable certification frameworks, and relevant PHD students). Such a diversity of actors was chosen with the goal of gaining insights into the opportunities and barriers related to implementation of CE in the building industry from many different perspectives. Interviews were first conducted with Danish CIRCUIT project partners from which key themes were gleaned. After a handful of interviews, it become apparent that including building industry actors outside of the CIRCUIT project would be important to painting an accurate picture of the current context. These secondary actors were identified as having an important role in shaping discourse around CE and sustainability and or having an influential role in shaping Danish policy. Such actors were interviewed using the same approach applied in interviews with the CIRCUIT partners.

The first round of interviews was conducted in a semi-structured way, in which the aim was to be open and extensive with the aim of better understanding the interviewees work and organization (Czarniawska, 2014; Hansen, 2009). A template was created for the interviews that was used to facilitate discussion and ensure there was thematic consistency across the interviews. However, the author used what she was learning throughout the interview process to improve the template for better suited discussion. Documentation of the empirical data generated by these interviews is presented in Chapter 6.

The general aim of these interviews was to gain an overview of what building professionals, involved in CE innovation projects, identify as opportunities and barriers to implementing circular economy within the building industry. The interviews served as a comparison to the literature review, so that it could be better understand how theoretical concepts were (or weren't) being applied in practice and to see if the literature accurately reflects the reality Danish building industry actors experience in practice.

The interviews were conducted and recorded digitally on Zoom. During the interviews, notes were taken to highlight points of interest, after which the audio files were transcribed using Konch software. Transcriptions were edited for typographic errors. Finally, the empirical data from the interviews were coded and visually mapped as pictured in Figure 8 & 9. A schedule of the interviews, meetings, and workshops that resulted in the empirical data for this study can be seen in **Figure 6**.

3.1.2 Participatory workshops

Workshops were used in this study as a way to generate feedback from collaborators on the design of a Collaboration Tool, the results of which are presented in Chapter 8 – Design Space. In the first series of workshops the Assumption Game was used as a Boundary Object (Star, 2010) to facilitate discussion with the collaborator. After the Assumption Game was played, actors were briefly introduced to a draft version of the Collaboration Tool and were asked to provided general feedback. This proved to be a useful step in formalizing the specification for the Collaboration Tool. Furthermore, these feedback sessions were useful defining where the author should be more articulate in the description of such a device.

A second workshop was held in-person with the collaboration partner Lendager Group, in which the author was able to present a more developed iteration of the Collaboration Tool. This co-creation step was vital step in the development of the Collaboration Tool, as Lendager we be the primary user of the tool. Engaging Lendager Group in the process of co-creating the tool improves the likelihood it will be implemented and experimented with beyond this thesis in the context of actual collaboration projects. A more detailed description of the iterative process by which the Collaboration Tool was generated is articulated in the Design Space – Chapter 8.

3.1.3 The Assumption Game

Based on knowledge gathered during the first-round interviews and literature review the author was ready to test assumptions and initial findings accumulated along the way. As a method of testing assumptions and generating empirical data, the author created a boundary object called "The Assumption Game." The goal of testing assumptions was to gather inputs, co-create, and validate initial ideas for the design space with the CIRCUIT partners.

The Assumption Game was formatted on Mural and was conducted online during a one-on-one workshop, with CIRCUIT partners Figure #. The Assumption Game consisted of 3-decks of cards organized in the following categories: "Collaboration", "Innovation", and "CE Processes". The text written on each card is representative of themes generated during the discovery process. The Researcher and the "player" read through the cards together and the "player" was asked to place the card along a qualitative spectrum: "Yes, definitely", "Kind of, sorta, maybe", "No, not really" or "I am not sure." The players were free to discuss or elaborate on their card placement, and often gave examples of how it applied in the context of their experience within the context of circular building projects. The players were given the option to create new cards which more accurately represented their experience, which resulted in the deck of cards expanding between each game. As

Date	Particiapnt	Description of interaction
First Round - Interviews		
24/11/2020	Circular Consultant - Lendager Group	Semi-structured Interview with CIRCUIT partner
25/11/2020	Architect - Lendager Group	Semi-structured Interview with CIRCUIT partner
25/11/2020	Demolition Safety, Engineer - Niras	Semi-structured Interview with CIRCUIT partner
10/02/2021	Demolition, Sustainable Development Manager - J.Jensen	Semi-structured Interview with CIRCUIT partner
16/02/2021	Contractor, Head of Sustainability - Enemærke og Petersen	Semi-structured Interview with CIRCUIT partner
19/02/2021	PM, Sustainble Construction & Reuse - City of Copenhagen	Semi-structured Interview with CIRCUIT partner
25/02/2021	CE Lead, DGNB-consultant - City of Copenhagen	Semi-structured Interview with CIRCUIT partner
01/03/2021	PM, Urban Renewal - City of Copenhagen	Semi-structured Interview with CIRCUIT partner
08/03/2021	PHd Circular Construction - DTU	Semi-structured Interview with CIRCUIT partner
12/03/2021	CTO Material Passports - Sundahus	Semi-structured Interview with industry expert
12/03/2021	PHd Circular Tenders - Enemærke og Petersen, AAU, CBS	Semi-structured Interview with CIRCUIT partner
16/03/2021	Technical Director, DGNB	Semi-structured Interview with industry expert
17/03/2021	Circular Project Lead - Realdania By og Byg	Semi-structured Interview with industry expert
17/03/2021	Technical Manager - DK-GBK	Semi-structured Interview with industry expert
18/03/2021	Bolig- og Planstyrelsen Frivilligt Bæredygtighedsklasse	Semi-structured Interview with industry expert
Second Round - Workshops		
12/04/2021	PM Sustainble Construction & Reuse - City of Copenhagen	Workshop with Assumption Game & Collaboration Tool
12/04/2021	PM Urban Renewal - City of Copenhagen	Workshop with Assumption Game & Collaboration Tool
14/04/2021	PHd Circular Tenders - Enemærke og Petersen, AAU, CBS	Workshop with Assumption Game & Collaboration Tool
15/04/2021	PHd student Circular Construction - DTU	Workshop with Assumption Game & Collaboration Tool
15/04/2021	Head Consultant, DGNB-consultant - City of Copenhagen	Workshop with Assumption Game & Collaboration Tool
15/04/2021	Contractor, Head of Sustainability - Enemærke og Petersen	Workshop with Assumption Game & Collaboration Tool
Third Round - Feedback Sessions		
29/04/2021	WP4 CIRCUIT Partners, 8 participants	Presentation of project findings & Collaboration Tool
11/05/2021	Lendager Group Circular Consultancy Team, 12 participants	Presentation of project findings & Collaboration Tool
13/05/2021	Lendager Group Circular Consultancy, 8 participants	Online brainstorming & co-creation of Collaboration Tool
Collaborator Meetings		
29/01/2021	Tim Tolman, Team Leader Lendager Circular Consultancy	Introduction to CIRCUIT and collaboration guidelines
25/02/2021	Tim Tolman, Team Leader Lendager Circular Consultancy	Potential project directions, project structure
01/04/2021	Tim Tolman, Team Leader Lendager Circular Consultancy	Review of project findings and ideation of Collaboration Tool
Industry Events		
10/03/2021	Bæredygtig Byggeri - GBK-DK	Online conference , DGNB Certification and Circularity
20/04/2021	Bæredytige Renovering - REBUS	Online conference, sustainable renovation methods
14/04/2021	Sustainable Building Process - Værdibyg	GreCo, online lecture, sustainable processes
12/05/2021	From Waste to Gold - Konstruktør Foreningen	GreCo, online lecture, construction site waste re-use

Figure 6

the facilitator of the game, the author only asked follow-up questions when something the player said wasn't clear to them or if an interesting point needed more elaboration. By analyzing the results of the Assumption Game it was possible to identify where there is consensus and or diverging ideas related to different aspects of collaboration in circular innovation projects. The results of the game will be discussed in the Chapter 7 and are formatted in **Figure 7**.

Six CIRCUIT partners, most likely to use the collaboration tool in their own work were invited to the second round - workshop. As such, those who participated in the Assumption Game have roles such as resource coordinators, project managers, or circularity specialists within their respective organizations. Findings from the Assumption Game were used to generate a detailed specification for the collaboration tool and are documented in Chapter 7.

3.1.4 Industry events

Throughout this thesis the author attended industry events held online that were pertinent to the study, as illustrated in Figure 6. These events are a window into the Danish building industry and are reflective of how the industry is shaping discourse around CE. Such events are evidence of how organisations are legitimizing CE as a viable pursuit and how organizations aim to position themselves within the discourse. Some of the actors included in this study were key note speakers at such events, thus it provided insights into their meaning and ambitions outside of the interview setting. This aided in generating a more dynamic and in-depth conservation during the interviews in which the author could "follow-up" on information communicated during the events.

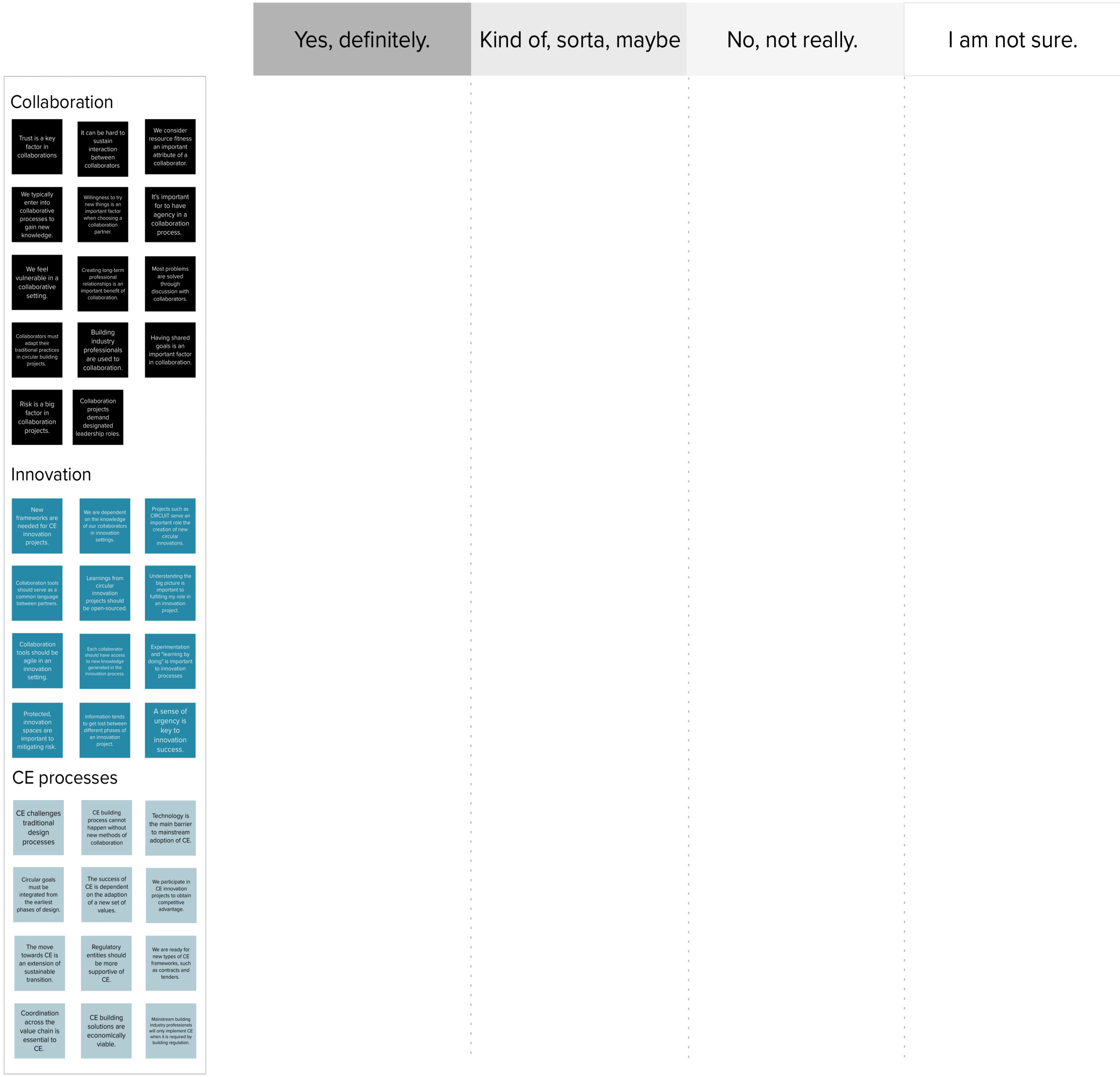


Figure 7
The Assumption Game Template

3.2 Making sense of the empirical data

In this section of the report, methods used to make sense will be made of the data generated in this study will be described. The methods chosen were used to make visible particular aspects of the data as it was generated and to make visible by the process by which this study was conducted.

3.2.1 Coding and visual mapping of data

Through the "process of discovery" (Czarniawska, 2014) the digital whiteboard platform Mural was used to visualize and document findings throughout this thesis. The Mural boards were used in lieu of project A3 "worksheets" typically used in the Sustainable Design Engineering program. These boards were used to document findings and track progress for internal purposes, as well as to communicate with external participants, such as the project advisor and classmates during milestone presentations. The boards were used to visually map and code data from interviews, as well as sketch-out initial design ideas. All relevant Mural boards can be found in the Appendix, where they can be explored in depth.

A pragmatic approach was taken to coding the empirical data acquired in the First Round - Interviews, in which the author looked for similarities, contradiction, variation, and interesting phenomena. The aim was not to over categorize or fixate on a specific number of stories or themes, but rather to apply the process of abductive thinking; in which seeing patterns and revealing thematic structures is central (Czarniawska, 2014; Hansen, 2009).

The aforementioned platform Mural was used to create a visual mapping of the empirical data in a two-step process. Digital post-it notes were used to represent a single idea, thought, theme, or quote. In accordance with grounded theory approach, the collection of empirical data, it's classification and interpretations were conducted in a simultaneous manner (Czarniawska, 2014). This process started by listening to audio recordings of the interviews and sorting the themes brought up by each actor. A choice was made to organize the post-it's in accordance with theory presented Chapter 3: Technical, Institutional, and Behavioral lock-in categories (Unruh, 2000; 2002). In this first phase of mapping **Figure 8**, each actor was given a unique color post-it – so it would be possible at a later point, to identify which ideas were important to different actors the building value chain.

In the second phase of mapping **Figure 9** post-its were color-coded according to the aforementioned categories of Technical, Institutional, and Behavioral. Next, a visual mapping of the empirically collected data was mapped in which a) each idea or theme was given a post-it, b) ideas that are related in some ways categorically were placed nearby each other, c) groupings were classified with thematic headers and finally d) the author looked for connections among the categories (represented by arrows). By conducting such a process, it was possible to identify emerging categories for further study, while also better forming an understanding of how the technical, institutional and behavioral lock-ins are interrelated and co-evolving (Unruh, 2000; 2002). Both the first and second phase of Mural maps can be found in the Appendix.

3.2.2 Mapping the building process

From the onset of this thesis, it was clear that mapping the building process would be key to contextualizing many aspects of the study. Using the aforementioned digital platform Mural the building process was diagrammed Figure 10. Following the "logic of discovery" the building process mapping was refined throughout the course of this study, where more layers of information were added. Figure 10 is a visual compilation of information processes from the authors professional architectural experience, from information gleaned in the literature review and from the empirical data generated through the interviews and workshops. The mapping of the building process will be used to articulate phenomena discussed throughout this thesis, in which cases it will be given more detailed descriptions.

Figure 8
First phase of mapping on Mural

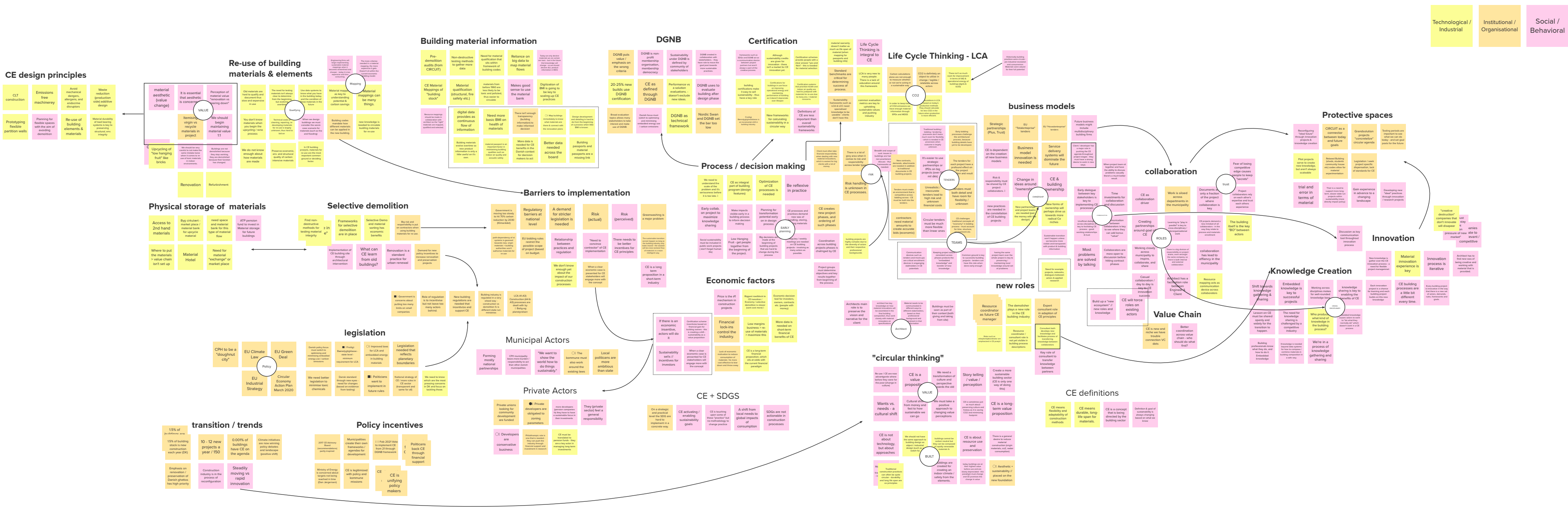


Figure 9
Second phase of mapping on Mural

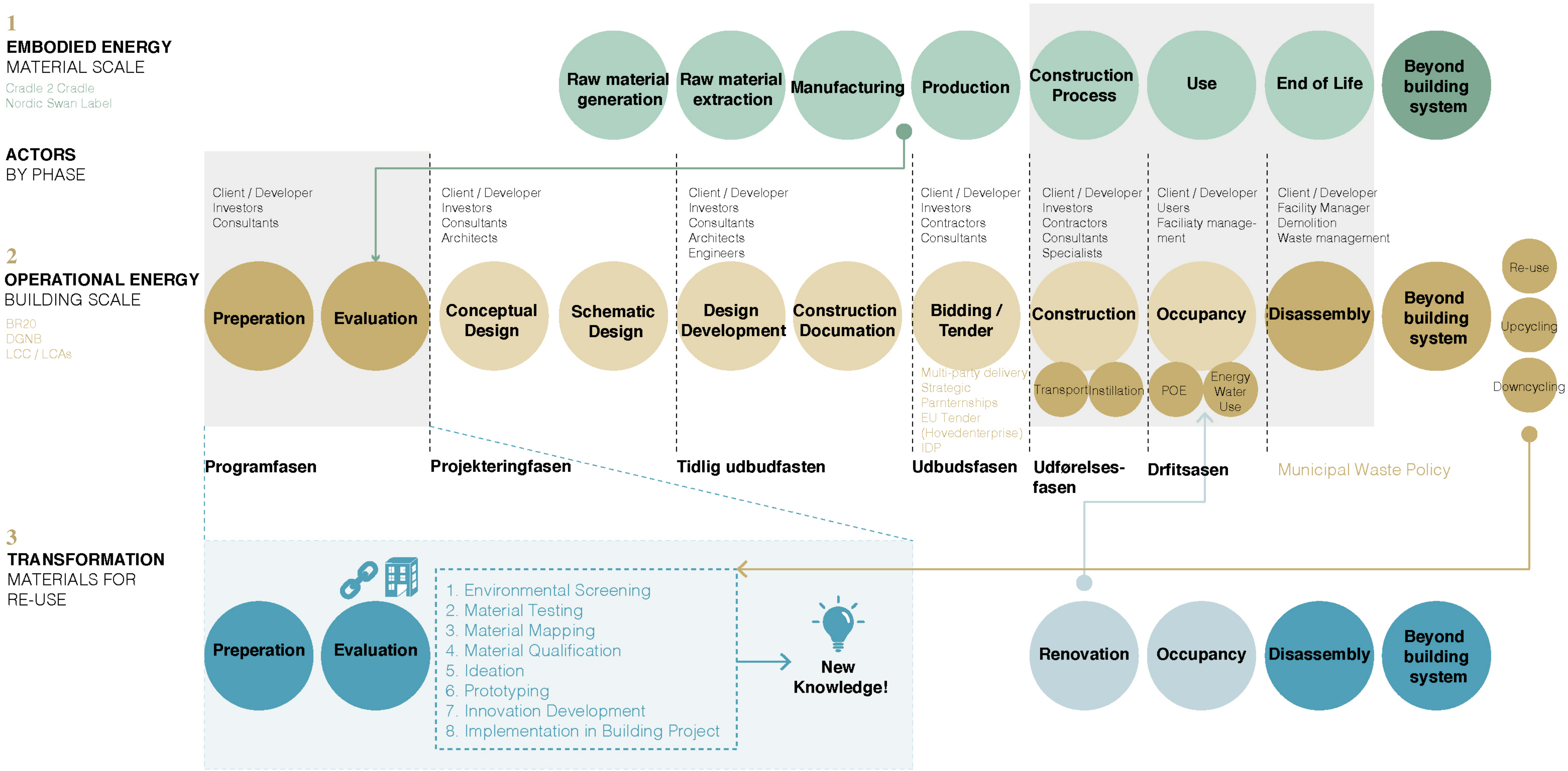


Figure 10
Building phase

1 A lot of the literature on CE deals with circular principles on a material level, with focus on re-circulating materials for productive use. Despite this, many of the LCA approaches used to evaluate CE products are reflective of linear thinking.

2 The building process is mapped, with darker colors symbolizing CE principles. Many of the benefits of CE processes are not included in analytical frameworks, thus hold little “value” when calculating for sustainability.

3 Transformation projects have a tendency to have a much more in-depth evaluation phase which is characterized by the investigation of the existing building stock. Today’s methods for doing so are highly analogue. In the future, such steps will be aided by technology.

3.3. A Literature Review

A literature review was conducted parallel to the generation of empirical data in this thesis. The literature review served to: a) create an overview of the current state of integration of the CE in the building industry, b) create an informed understanding of the major problematizations and limitations of the CE concept and c) identify key areas that demand further research and practical insights. After six months of active research into the intersecting field of CE and building industry a level of 'theoretical saturation' (Czarniawska, 2014) was reached and culminated in 100 pages of literature review summary.

The literature review was written with "snowballing" accumulative effect throughout the course of this study. As new articles were read, and new phenomena or points of interest were uncovered the author combed through the references section of each article for other relevant literature. In this way the study branched out from one article to the next. Furthermore, as "key voices" were identified in the literature they also became subject to research.

As a first step the author revisited all the academic articles on CE present in the academic curriculum from AAU's Sustainable Design Engineering program. These articles provided basic insights into the history of CE, how CE is articled as a general design concept, discourse on the limitations and major criticisms of CE and helped situate CE among other literatures on Design for Sustainability. Many of these articles focus on CE as it applies to the creation of new business models and transitioning from linear to circular production methods at a product level. Once familiarized with the basic discourse around CE the research branched out to include literature that focuses on CE and the building industry. As a starting point, the author searched through relevant literature published by Aalborg University's own BUILD department.

The literature review references academic articles found through Aalborg University's library data base, as well as industry reports, books and white papers. The author used Aalborg University's search machine Primo to find relative literature using many key words for example: "circular economy" "circularity" "CE" "circular economy building industry" "circular architecture" "CE and LCA" yielding in literature published between the dates of 2013-2021. In the second part of this thesis searches include topics such as "sustainable project management" "construction management and circular economy" "construction management" "iron triangle" "circular project management" yielding in literature published between 2000-2021.

CE is a relatively new concept thus does not yet have its own journal, school or definitive field of research. As a result, the literature on CE is quite broad and found in many different publications. Following the research methods described above the author found pertinent articles to include in this study in the following journals: *Administrative Sciences, Earth Environmental Science, Ecological Economics, Environmental Innovation and Societal Transition, International Journal of Information Management, International Journal of Managing Projects in Business, International Journal of Project Management, Journal of Cleaner Production, Journal of Industrial Ecology, Journal of Industrial Production and Engineering, Journal of Professions and Organisations, Nature Sustainability, Organization, Supply Chain Management, Supply Chain Management: An International Journal, Renewable and Sustainable Energy Reviews, Sustainability, Sustainability Science and Technological Forecasting & Social Change and Technological Forecasting & Social Change*.

The methods in this study resulted in many times of information generation that will be detailed and given context in the proceeding chapters.

4

LITERATURE REVIEW

4 Literature Review

This literature review is written in two sections. The first section 4.1 focuses on CE as it applies to the building industry and was written with the aim of identifying and analyzing barriers to and opportunities for implementing CE in the building industry. The second section 4.2 focuses on both tradition and sustainable frameworks for construction management and sustainable project management, where focus is on the role of sustainable consultants in the building industry.

4.1 Demand for sustainable transition in the building industry

As articulated in Chapter 1 the global building industry puts massive strain on our natural capital and Earth's ability to balance natural systems. There is immense opportunity and material potential within the existing building stock. In order to fully harness this potential building waste must be reframed as valuable material resource. In doing so new building industry practices and processes must be created to support this knowledge. (EMF, 2013; Jørgensen & Remmen, 2018) Buildings must be (re)conceived as 'material banks' in which materials are temporarily stored for later re-use. In doing so, the industry will become more resilient in the face of future material shortages. There will be a need to reconfigure institutional and technological norms so that the re-use of material elements and components becomes common place. The circular transformation of the building industry will result in "synergies, but also trade-offs, often times conflicting goals, which only become recognizable and solvable in an integrated, systematic approach" (Passer et al., 2020, p. 1161). We have to begin, using what we already have around us.

The "Renovation Wave" introduced in the European Green Deal is evidence of such an integrated, systematic approach and aims to stimulate the economy and help achieve climate targets. Simply repairing, retrofitting, and transforming the existing building stock will be more cost-effective and less resource intensive while meeting the needs for built structures. In Europe, 65% of the building stock demand for the next forty years already exists. It is calculated that of those buildings, 45% are 50 years or older – meaning we will have to get smarter and faster about how we renovate building and circulate materials for re-use (EMF, 2020). Such structures will need to be adapted for energy efficiency, improving comfort and lowering costs for residents. Applying the principles of CE introduced in this chapter will be integral to minimizing the building industry's impact within the time-frame set forth by climate policy (EMF, 2020). Pomponi and Moncaster (2017) argue that if even if circularity is universally adapted by mainstream building industry actors, focusing on new buildings won't be enough to meet climate targets. We must figure out how to work with the constraints of the existing building stock.

4.1.1 Defining circular thinking, principles, and methods for implementation

The concept of CE emerged in the late 20th century alongside environmental concerns regarding planetary resource exhaustion. CE's first appearance as a term was coined by Pearce and Turner (1990) where a case was made for the economic benefits of embracing environmental values. Their argument based on the earlier work of Boulding (1996)'s spaceman economy is that unlike the waste created by man-made systems, natural systems find a way to absorb and recycle nutrients. The authors argued for such "circular" material flows to be integrated in the man-made economy. (de Jesus et al. 2017) This concept has been echoed throughout environmental, scientific, and philosophical design literature from authors such as Michael Braungart and McDonough's Cradle to Cradle (1992), Gunter Pauli's Reduce, Re-use, and Recycle (1997), and Paul

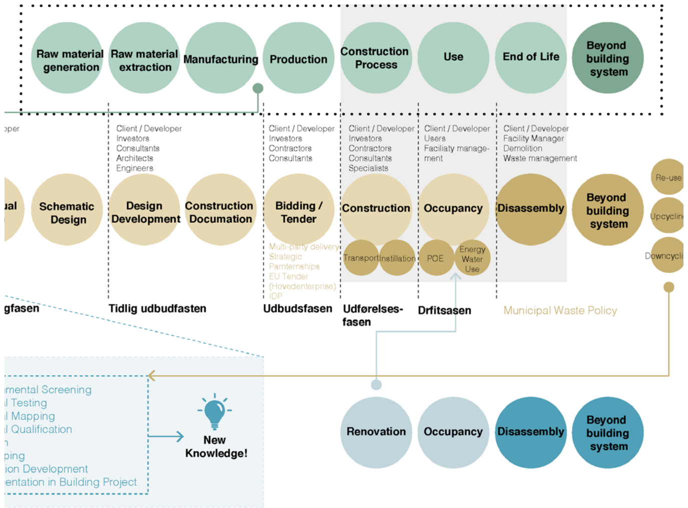


Figure 11
Life cycle approach, from raw material extraction through end of life

and Nancy Lovin's Natural Capitalism (1999), among others. CE made a resurgence with the founding of the Ellen MacArthur Foundation in 2010, where it has remained a fixture in sustainability discourse (CIRAIG, 2015; de Jesus et al., 2017; Monero et al, 2016).

Though a part of sustainability discourse, CE is not synonymous with sustainability. In some cases circular designs can be quite unsustainable. CE is criticizes for oftentimes overlooking social dimensions, thus should be used in conjunction with more holistic, sustainability frameworks (Schultz et al., 2019). CE and sustainability are said to have different origins, goals, motivations, institutionalizations and beneficiaries. (Geissdoerfer et al., 2017). CE's full potential is only achieved when applied systemically to design solutions (Monero et al., 2016). For these reasons, this thesis study frames CE from the systemic approach of sustainable transition studies.

CE is an emerging concept that has been defined as management tool for inter-organizational, sustainable development and transition (Korhonen et al., 2018). CE has been defined as "a multi-level, socio-constructed concept that can either be considered a paradigm shift, a new toolbox, a conceptual umbrella or a portmanteau discipline" (CIRAIG, 2015, p. xi). CE has also been described as a "journey" one might take when transforming production practices from linear to circular (Hill-Hansen, 2021; Jørgensen & Remmen, 2018). CE is also identified as "an industrial system that is restorative or regenerative by intention and design" (Monero et al., 2016, p.6) and is described as abundant, innovative, and prosperous - working to preserve and optimize through efficiency.

CE is sometimes referred to as "circularity or" circular thinking. Circularity proposes flipping the traditional design process on its head, where the idea should begin with "the end of life" and problem solving should happen in reverse. CE embodies a life cycle thinking approach in which the steps of raw material generation, raw material acquisition, material manufacturing and production, use, end of life, and re-introduction to material cycles are considered for their resource use implications and negative externalities. Such a life cycle approach is mapped in **Figure 11**.

Due to ambiguity of CE, it is necessary within each building project to specify which definition of CE is being applied. Given CE's breadth, arriving at a distinct definition is somewhat tenuous and often means something entirely different to different actor groups (de Jesus et al., 2017). Lack of consensus about the definition of CE within the building industry is identified as one of the key barriers towards mainstream implementation (Eberhardt et al., 2019; Korhonen et al., 2018).

The definition of CE that is accepted in this report is one defined by the EMF (2019) as a concept that has the intention of designing out waste, while regenerating biological systems so that human beings can thrive within Earth's planetary boundaries. It is the belief of the author that applying circular principles to building industry practices will help push the building industry towards a sustainable transition, so long the amount of virgin material throughput flow remains under a level that nature can tolerate. It is the author's belief that if and when CE becomes a mainstream building industry practice, it can serve as a form of inter-organizational, sustainability management framework(Korhonen et al, 2018). CE in the building industry will first succeed when there is an "economy of scale" (Lendager & Vind, 2018) and new value chains emerge, ensuring material circulation at a local level, where methods for doing so can replace linear building industry practices of today (Sachs et al., 2019; Korhonen et al., 2018).

Figure 12
Slowing, Closing, and Narrowing Resource Loops.
(Hill-Hansen, 2021)

There is a significant body of literature on methods for implementing CE within the frame of "slowing, narrowing, and closing" of material loops (Bocken et al., 2016) all of which borrow from core philosophies described in Cradle to Cradle: Remaking the Way We Make Things (2002) by Braugart and McDonough, in which technical and biological nutrients are recognized as separate material flows and the upcycling of such nutrients for equal or greater value is prioritized (Hill-Hansen, 2021).

Slowing material loops (Figure 12) is all about product life extension through strategies such as maintenance and repair, slowing down the flow of virgin materials use. Narrowing material loops is all about using fewer materials per production unit. Finally, closing material loops focuses on closing the loop between "end-of-life" and "production" through recycling, thus closing the loop (Bocken et al., 2016). This framework is expanded upon and is often framed through five umbrella design strategies: design for circular supplies, which focuses primarily on returning materials to biological cycles and aims to use waste as value resource; design for resource conservation, in which emphasis is place resource optimization such as additive design practices; designing for multiple cycles which focuses on durability and prolonging material use through recirculation; design for long life use of products which emphasizes prolonging the use-phase of a product through strategies of reuse, repair, and upgrading - often resulting in product service systems; and design for systems change refers to designing for complex, multi-level system integration (Circularity City, 2018; Lendager & Vind, 2018; Monero et al, 2016).

These core CE definitions and strategies have resulted in a wide range of circular building principles (Figure 2) described across the literature and demonstrated in practice. Many of these circular building methods are applied at either the product scale or the urban waste stream scale. Very little of these methods have been actualized at the building scale. There is a need for more case-study research and demonstration projects in this area, because the building scale has the potential to be an activator of CE at the other two material levels (Giorgi & Gampioli, 2020). To better contextualize the empirical data covered in this thesis study, the slowing method circulating building materials for re-use will be expanded on in the following sub-section (Hill-Hansen, 2021).

4.1.2 Circulating building materials for re-use

In order for CE to fully support sustainable transition, there needs to be a fundamental shift in the way material worth is preserved, and a re-framing of the way waste is defined. This will first come with a dynamic shift in mind-set, in which we stop seeing resources as infinite and inexhaustible (Beim et al., 2019; Rockström, 2015; Sachs et al., 2019). Today, there are no standard metrics to determine the exact moment when building materials become waste: "When waste is perceived as a resource for materials or for energy, the flow has an economic value…Therefore, a consensus on what is usable and what is not is very important for the ideals of circular economy to contribute to global sustainability" (Korhonen et al., 2018, p.45). More often than not, building materials are designed to last much longer than a buildings' anticipated use. There is a need to identify whether materials lose their value due to technical obsolescence (when repair or upgrading isn't viable) or rather from emotional obsolescence (a desire for newness, more value based) (Jørgensen & Remmen, 2018). These challenges demand significantly different solutions. GXN Innovation (2018) suggest designing materials for appropriate life-spans and flexibility **Figure 13**.

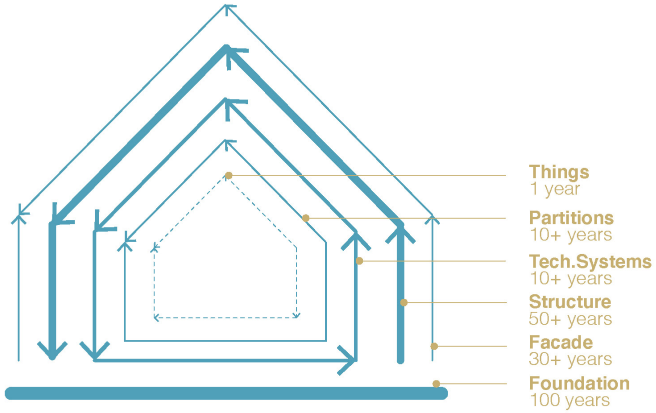


Figure 13
The thickness of lines is relative to the embodied energy of materials, and the potential length of their lifespan, and relatively flexibility. For example, foundations made of concrete are quite hard to recycle in a way that preserves their material integrity, where as facade systems can be designed as product services systems and change with the function of the building.
(GXN Innovation, 2018)

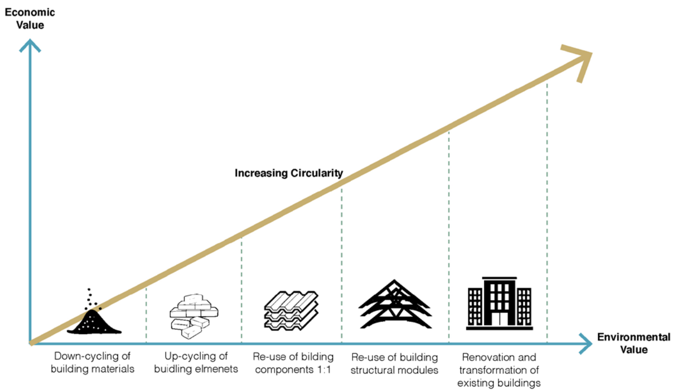


Figure 14
Conceptualizing the economic and environmental value of materials for re-use.
(Inspired by: Eberhardt et al, 2019)

In the re-framing of the way we conceive buildings "We must give up the 'consumer mindset' (i.e. purchase, use, (build less!), and use what we already have, both in terms of materials and existing buildings" (Beim et al., 2019, p.21). We must begin designing buildings with the mindset in which buildings are perceived as "material banks" for temporary storage (Malmqvist at al., 2020) and begin implementing slowing, narrowing, and closing methods prolonging material life. Although the construction industry has well-established recycling practice, emphasis has been placed on urban-scale, waste streams in which materials are down-cycled for a lower material and economic value (Eberhardt et al., 2019; Hill-Hansen, 2021; Lendager & Vind, 2018). We must begin harvesting materials from the existing building-stock in ways that preserve material structural integrity, economic worth and social value.

There are many strategies for re-using materials, as illustrated in **Figure 14** not all of which have equal economic or environmental consequence. For example, when building materials are down-cycled, such as the common practice of crushing bricks for gravel-fill, significant material value is lost. Whereas, bricks held together by lime mortar can be re-used again in new construction, preserving their material integrity. In comparison, when a brick building is renovated, the material integrity is preserved and the time and cost associated with selective demolition is forgone, as is the emissions related to transportation. In relation to the aforementioned "renovation wave" the principles of circularity increase when adjustments are made through retrofitting techniques, which allow the carbon intensive building structures such as steel and concrete to remain in place.

The benefits of such circular practices include material cost savings in construction budgets, significant reduction of C02 emissions and building embodied energy, as well as more qualitative value creations such as unique aesthetic qualities and preservation of architectural identity (Bertelsen et al, 2020; Lendager & Vind, 2018; Hill-Hansen, 2021). In the Dwanish context, under 2% of the building stock consists of new building projects annually (PhD Circular Construction, personal, 8 March, 2021), meaning a majority of construction projects deal with building transformation and material re-use. Despite this common practice, there is a lot of information needed around the ways in which buildings are currently renovated. Furthermore, there is a need to better understand and document the treatment existing materials, many of which were created with dangerous chemicals and assembled from a cradle-to-grave mindset. In order to maximize material potential of the existing building there is a need for "improvement in knowledge, skills, and relationship between the members of supply chain, and the inclusion, from the early design stage, of new operators" (Giorgi & Campioli, 2020, p. 294).

In order for circular building practices to go from niche to mainstream there are key problemetizations to overcome, which will be detailed in the following sub-sections.

4.1.3 Barriers towards implementation of CE

The building industry is defined by short-term contracts and economic turn-overs, meaning market mechanisms do not align with the long-term propositions of CE principles. In general, there is an assumption that circular building process are more expensive and there is a need cases which counter act this stigma (Eberhardt et al., 2019; Hill-Hansen, 2021). The building industry is dominated by project management frameworks "iron triangle" as the key metric for success. Such a framework is terribly limiting in construction projects that work towards implementing innovative solutions, which inherently are reliant on extra resources. This particular management framework will be expanded upon in Chapter 4.2. In their study, Giorgi & Campioli (2020) found that investors have little to no knowledge on their building-stock and quantity of material output. Because of this they are indifferent to recovering the material harvest value. They suggest that well-documented, pre-demolition audits can serve as a knowledge object between different actors and work to communicate this under documented information. In general, the economic and environmental benefits of preserving the existing building stock must become more readily visible.

Furthermore, the fluctuating market for recycled materials make project economy hard to predict and this lack of access to materials (quantity, when they might be available, transportation and storage logistics) risks slowing down building processes (Bertelsen et al., 2020; Hill-Hansen, 2021). Time is money! Furthermore, governing bodies do very little to hold building developers responsible for environmentally derogating externalities –making it hard for sustainable building materials and design solutions to compete with cheaper alternatives. When factors such as embodied energy are better integrated into building codes, it will become too expensive to use virgin materials. At the moment, it's too expensive to re-use materials because of the extra steps involved in qualifying the materials for re-use. Furthermore, powerful institutions, which enable tax subsidies, fiscal policies, as well as investment programs must work to create new conditions in which there is profitable and competitive conditions for CE. For example, waste management policies have a direct impact on the amount of resources diverted or recycled from waste streams (Monreau et al., 2018).

There is a need for basic material documentation which qualifies and certifies building materials for re-use through non-destructive testing methods. Such information can be made accessible through the use of material passports and integrated material banks and will enable better targeted renovation projects. Such strategies can be facilitated through enabling technologies such as blockchain, BIM, and laser-scanning (Ahmed, 2019; EMF, 2020; Harty, 2019, Valeche-Altinel et al, 2021). Until these digital tools are widely available and integrated into project workflows, the process of material procurement and documentation is quite arduous and analogue, which deters the "scaling-up" or "economy of scale" needed for CE to thrive in the building industry (Lendager & Vind, 2018).

Additionally, buildings are a complex compilation of many material elements, each of which have their own life spans, material value chains, and warranties, meaning the materials should be phased out of buildings at different times, thus buildings should be viewed as "a system of temporary storage and constant flow of resources that needs to be managed individually" (Eberhardt et al., 2019, p.6) Depending on the material composition and assembly of a building there are varying levels of maintenance and quality. Therefore, buildings should be designed with building elements and product life-cycles in mind (GXN Innovation, 2018; Eberhardt et al., 2019; Eberhardt et al., 2020; Pomponi & Moncaster, 2017). Current technology is lagging behind demand. While there is knowledge on material passports and whole building integration – most of these tools are designed for application within new buildings. We simply don't have this information for the existing building stock.

4.1.4 Tools for qualifying and organising CE projects

Building industry practioners are currently not incentivized by building regulations to practice circularity. There is a need for public policy which reflects a circular mindset, limits the reuse of raw-material extraction and better facilitates CE procurement processes (Beim, A. et al, 2019; Giorgi & Campioli, 2020; Monreau et al., 2018). Project infrastructures such as contracts, tenders and even sustainability frameworks such as DGNB are created for linear, new building projects. This means that the obstacles presented in transformation projects for material re-use are not well-addressed, creating a demand for new frameworks which enable CE building principles.

One of the most common metric used for measuring sustainability in the building industry are Life Cycle Assessments (LCA). While the Danish building industry has a standardized method for calculating "LCAbyg" LCAs are not one size fits all and never totally objective. While they are useful for documenting the sustainability outcomes of building projects, they are not yet adapted to include the CE building principles. For example, they do not include transportation related carbon emissions, and do not include deconstruction and demolition. Meaning that when locally harvested, upcycled building materials are included in a building project they are calculated to have the same embodied footprint as virgin materials sent from another continent. Furthermore, LCAbyg does not include anything "beyond the building system" (**Figure 15**) meaning, buildings that are designed for disassembly have no carbon offset (Lendager & Petersen , 2020). While this is just one of the many analytical aspects used to measure the sustainability outcomes of design principles, it is evidence of the building industry's failure to adapt to CE value propositions in a timely manner. (Eberhardt et al., 2020; Lendager & Petersen, 2020; Malmqvist et al., 2020). Furthermore, building regulations and contracts tend to favour linear thinking, and short-term agendas whereas the benefits of CE are maximized in the long-term (GXN Innovation, 2018; Eberthardt et al., 2019). For example, building codes primarily set requirements for building efficiency and operational energy which creates misjudgements about the sustainability of buildings, and results in burden shifting (Passer et al., 2020).

Due to issues of liability, risk and ownership over buildings the construction industry is very conservative. This is reflected in industry standards such as construction directives and sustainability certifications, which are not designed to operate with recycled materials. As such, contractors are reluctant to use recycled materials due to a lack of installation manuals and product guarantees (Bertelsen et al., 2020; Hossain et al., 2020). Eberhardt et al. (2019) note: "the varying goals and focuses of stakeholders, cause the different stakeholders to work against each other to achieve the largest profit margin of the respective building project, leading to insufficient collaboration and mistrust" (p.4). To overcome such institutional and behavioural obstacles, Bonoami (2020) suggests adapting co-creation practices in which collaborators experience mutually beneficial learning processes and project outcomes "This translates into the strategy of fostering interactions, rather than transactions, and facilitating partnerships rather than (business) relationships" (p.226). Currently literature on CE identifies these issues but does not address them through concrete studies.

Therefore, there is a demand for new ways of communicating and organizational projects so that

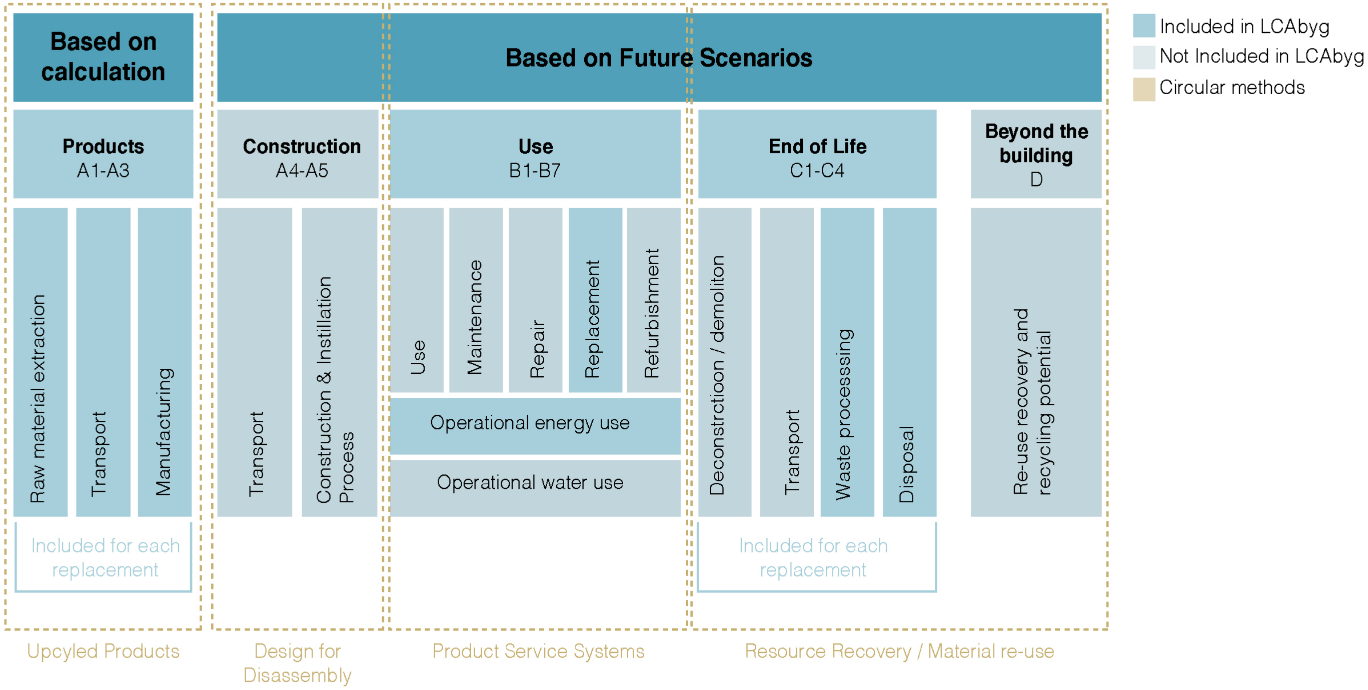


Figure 15
LCAbyg framework is inherently based on linear building principles and is not conducive to the long-term benefits of CE building principles.
(Inspired by: Lenadger & Petersen, 2020)

Qualifying Tools

Characteristics
• Tendency to be quantitative
• Measure the output of building project (cost, carbon output etc.)
• Comparative

Examples:
• Life cycle assessment, Life cycle costing, Total cost analysis, Material Flow Analysis, System Dynamic Assessment
• Certification schemes such as Cradle to Cradle, BREAM, DGNB, LEED
• Industry standards such as Environmental Product Declarations, other types of material data sheets

Organizing Tools

Characteristics
• Tendency to qualitative
• Focus on process and collaboration
• Learning oriented

Examples:
• New business models & Non-traditional contracts with focus on multi-disciplinary approach such as Integrated Project Delivery & Multi-Party Construction Agreements
• Material market place for 2nd hand resources
• BIM / Material Passport integration in process
• Vision creation workshops and collective incentive built in
• New design and innovation processes
• Re-design of Value Chain and Network

Figure 16
Building Industry Tools
(Inspired by: Leising et al., 2019)

the management and documentation of independent materials value chains is legible across building industry professions (Ahmed, 2019; Blomsma et al., 2019; Bocken et al., 2016). Throughout the CE literature many authors write about analytical tools and frameworks used to evaluate CE projects in terms of their quantitative, environmental, and economic impact such as carbon savings, energy usage, materials in tons, economic costs etc. While analytical tools play a critical role in evaluating the sustainability implications of circular building methods, they contribute little to building critical knowledge on how to facilitate circular building processes. In order for the on-going CE demonstration projects to contribute towards the development of sustainable transition, the processes by which they are conducted should be documented and key findings should be shared beyond the project boundaries. Pomponi and Moncaster (2017) write “There is clearly a strong need to accelerate behavioural research in built environment …it is apparent that it is people, rather than technologies, who are the key to embracing circularity” (p.716).

Very few authors have written about organization tools and process frameworks used, making the implementation challenges of CE building projects largely unknown. At the same time, the literature unanimously identifies a need for establishing new processes to facilitate communication across value chains (Blomsma et al., 2019; Bocken et al., 2016, Leising et al., 2018; Lendager & Vind, 2018; Malmqvist et al., 2020) as well as new tools for collaboration among actors (Hossain et al., 2020). Examples of such qualifying and organizing tools are highlighted in **Figure 16**.

Blomsma et al. (2019) argue that very little has been done to create “prescriptive methods” for the co-design of circular economy value chains. The successful implementation of CE projects is dependent on the project managers ability to select strategic partners, know when to engage them, and to what capacity. It is also argued that knowledge creation and willingness to share such value created with both internal and external networks is needed: “A shift in perception is necessary, that not only includes the generation of shared value, but also shared ownership and risk sharing with regards to creating and maintaining circular material resources (CMRs) and organization resources” (p. 3146). There is a need for better coordination of actors across the value chain.

Circular building projects demand a highly interdisciplinary approach to problem solving, which should include as many value chain actors as possible. As the “scaling up” of circularity happens over time, so does the complexity of stakeholder and collaborator involvement. Therefore, future collaboration tools for circularity must be based on systems integration, focus on the development of a shared vision for each building project and new ways of documenting the building processes – integral to “high order learning” (Brown & Vergragt, 2008; Bonanomi, 2020; Leising et al., 2019; Pomponi & Moncaster, 2017).

“The building process should become more integrated in order to enable project stakeholders to input their specific knowledge since the early phases of process” (Bonanomi, 2020, p.226). Doing so, will strengthen networks leading to development of stronger value chains. Furthermore, “CE’s own nature as an integrative multi-actor approach, points to the importance of networks for: building capacity; increasing cooperation in research and investment; sharing materials and by products, and; managing common utilities and infrastructures” (de Jesus et al., 2017, p.3009). In order to make such changes, more research must look into the social process that constitute actor behaviour, of which as potential to contribute towards, or deter from routine the changes of institutional norms (Schultz et al., 2019). Furthermore interdisciplinary innovation and research will play a key role unlocking the potential of CE "for its ability to switch from a narrow technical focus to a wider research basis," (Pomponi & Moncaster, 2017, p.717) which includes the role of individual and societal behaviour.

In order for mainstream adoption of circularity in the building industry to be accomplished before we reach Earth's tipping points "There is a need to focus on interdisciplinary knowledge sharing and co-production, and the holistic assessments of solutions against social needs, as well as the technical material outcomes" (Malmqvist et al., 2020, p.14). The concept of CE's social and institutional dimensions are still lacking and there is a demand for increased understanding of CE among building industry actors in which the implications of such measures are made visible to between actor groups (Houssain et al., 2020, p.10). "Circularity requires changes in the way companies generate value, understand and do business. Companies are compelled to interact within an ecosystem of actors, moving from a firm-centric to a network-centric operational logic" (Pieroni et al., 2019, p.199) which requires business model innovation, to prioritize the decoupling of value creation and re-source consumption. Such goals will be assisted through the development of new actor roles in the building value chain (Ahmed, 2019; Gluch et al., 2020) and new tools for collaboration which work to employ systems-thinking in a practical setting (Bocken et al., 2016; Leising et al., 2019) and move work to move beyond the limits of traditional construction management frameworks.

4.2 Construction management

There isn't one particular field of research that encompasses circular innovation projects in the construction sector, as this approach is new and novel. Therefore, it is necessary to draw on knowledge across research domains and look into the intersecting topics of sustainability and circularity as they are discussed in construction project management. The following subjects will review themes foundational to traditional construction management and the influence of sustainable project management on construction projects. In doing so, the aim is to identify institutional and behavioral norms of the construction industry, while also identifying methods for coping with these for sustainable ends.

4.2.1 The "Iron triangle"

Traditional Project Management (PM) frameworks are scoped on short-term, time bound problem solving, such as the Iron Triangle (IT), while sustainability issues, which can be defined as "wicked problems" (Rittel & Weber, 1973) are dealing with the long-term challenges of while there is no clear solution (Sabini et al., 2019). IT also known as the Triple Constraint is a central concept to project management practices and works to making visible key performance criteria: "time, costs and quality." In general, it is accepted that IT is used for its simplicity and applicable use in multidisciplinary project contexts. The reliance on IT is greater in projects that have uncertainty, complexity and have high risk for costing more than anticipated or going over schedule, such as the construction projects. Following trends of organizational studies, IT began emphasizing on participation, methods and practices which influence the perception of "success criteria" across project actors. This means that the IT expanded to include parameters of process and schedule maintenance as key components of the "time" criteria.

Although IT is highly functional it is often considered an oversimplification of project processes Simply being on-time and on-budget doesn't necessarily reflect the quality of the project results or working conditions (Jensen, 2013). Project management success is reflected by IT, but the process success (which includes project phase, type, satisfaction of stakeholders and ability to achieve strategic goals) can't be measured by the IT alone – thus construction projects often rely on project-specific, success frameworks, particularly in construction projects which work to integrate innovative solutions (Pollack et al., 2018).

The criteria of "quality" is heavily disputed in literature on IT, as this has to do more with project specific goals and long term objectives. Additional, "quality" is a phenomena not easily documented, or experienced universally by project stakeholders. Many argue "Quality" should be replaced by more descriptive terminology such as Scope, Performance, or Requirements - as these terms are more specific for each project (Jensen, 2013). Furthermore "quality" is the key metric to implementing goals such as sustainability into construction management. Therefore, additional sustainability frameworks which work to ensure social equality and efficiency in construction phases, must be implemented into zeitgeist of Sustainable Project Management (SPM) practices (Pollack et al., 2018; Sabini et al., 2019).

4.2.2 Sustainable Project Management (SPM)

SPM is an emerging field of which literature is sparse and discursive thus does not yet have a clear definition but often includes the following characteristics: a) considers environmental, social, and economic issues as interrelated; b) places emphasis on intergenerational equity; and c) works to achieve goals beyond existing laws and regulations. There is often a dimension of transparency in project development and proactive stakeholder integration in both project definition and development phases through co-creation. SPM works to create structure beyond the limitations of the IT and provide meaningful context to the "quality" metric (Sabini et al., 2019).

SPM is often implemented based on a client's moral imperative and ethical concerns to do more by way of our environment, with the simultaneous goal of achieving long-term organizational resilience. SPM is used to manage environmental trade-offs, analyze obstacles and ambiguities, and find balance between short and long-term objectives. SPM often applies a systems approach and works to situate the project within context of changing technical and institutional dynamics. The benefits of SPM are maximized when integrated into the core thinking and business dynamic of the organization. Within SPM for construction projects there isn't yet a clear framework for application, which is chalked up to the idiosyncratic nature of construction projects, in which building type, contracts and tenders, ownership models, location, and scale (among other factors) all play a major role in PM frameworks applied. Due to the complex nature of both construction management and sustainability concerns, there is a need for new tools which are both robust (a clear sustainability agenda) and flexible (to the spatial and temporal context) in nature. Sabini et al (2019) call for a radical change in construction management calling for the building industry to move beyond the IT and put "'projection' back into projects to create the 'future perfect' (Clegg et al., 2006) or the realization of a desired (sustainable) project outcome" (p. 834).

4.2.3 Short-term vs long-term sustainable proposition

The building industry is characterized by its project-based nature, in which new consortiums of actors are expected to work together, often for the first time. The result of such, is strong institutionalized project structure and actor roles or rather a pre-agreed "shared way of doing things" (Månsson, 2021, p. 6) which are slow and resistant to change (Van den Ende & van Marrewijk, 2014). On the other hand, the novel nature of buildings is characterized by a need for innovation: "Buildings are more or less unique prototypes and produced by temporary multi-organisations" (Gluch et al., 2020, p. 373). Often times the construction management institutionalized logic of IT is at odds with logic needed for innovative circular building projects. Furthermore, very little researcher has focused on the development of new actor roles, such as sustainability specialists, circular consultants, or resource coordinators, but rather emphasis has been placed on development of frameworks and assessment models, such as DGNB (Månsson, 2021).

Actors who are responsible for implementing sustainable solutions that challenge traditional project scopes and management frameworks (IT) which have embedded agency (understanding of social reality and norms) must deal with the "contradictory practices between long-term environmental strategies and immediate activities in construction projects" (Månsson, 2021, p. 3) while navigating the behavioral lock-ins of regulatory structures. Such actors can be thought of as sustainable project managers or knowledge brokers who work to navigate overall project structures while acting as radical change agents within the organizational structures where their individual agency is limited by institutional lock-in. Such actors must conduct boundary work (Bos-de Vos et al., 2019) to mobilize resources (financial, time, support of others) towards sustainability goals and visions of the overall project (Månsson, 2021). Such actors have a particularly key role in CE building projects, which require new interpretive frames.

There is a need for coordination (timing and continuity) between overall construction processes, and the innovation projects that often develop simultaneously. As project ideas evolve into technical solutions, additional external experts such as researchers are brought into the fold, as well as the new knowledge they contribute. Through this increased complexity and there is a need for purpose driven collaboration, which is often mediated by an internal project manager or sustainability specialist, who works to make sure the innovation process and representative actor groups are a) integrated into the construction process in an efficient manner and b) that new knowledge acquired is communicated to all collaborative partners in a timely manner. Such an actor must work to garner the agency and trust needed in such a leadership role. Through boundary work the project manager takes on the role as a knowledge broker (Kimble et al., 2010) and is often situated centrally within the innovation project. Such an actor should work to steer joint meetings, establish desirable routines, and enforce mutually agreed upon rules (Houssain et al., 2020; Gluch et al., 2020). The emerging management role of such a sustainability specialist, circular consultant, or resource coordinator is understood as critical in this thesis study.

5

THE SITE

5 Introducing the site

There are a growing number of CE initiatives in the Danish building industry. Lendager is known as one of the front runners in this arena, which makes them an interesting organization to follow, so as to get a better understanding of the barriers and opportunities for implementing CE in the Danish building industry. Lendager's team of material innovation specialists and circular consultants work to create circular material solutions using building industry waste. Much of this experimental work can be considered to exist largely in the niche level. As such, Lenadger often contributes their CE materi-al expertise in a collaborative setting with other pioneering building industry actors where the aim is to create new knowledge around material innovation, while proving to the industry case-by-case, that circulation of building materials for re-use is both a feasible and a sustainably just cause. For these reasons, CIRCUIT is a great avenue for Lendager to amplify their voice and create new net-works with like-minded actors. With these factors in mind, CIRCUIT was selected as the site for this thesis study.

5.1 About CIRCUIT

CIRCUIT is funded by European Commissions 2020 Horizon and is a collaborative demonstration project which involves 31 partner organisations across the building industry value chain in the regions of Copenhagen, Hamburg, Helsinki, and London. CIRCUIT began in 2019 and will run over a four year period. CIRCUIT is organized into 9 work packages (Figure 18) which focus on broad ranging topics from urban material flows and big data integration to focused pilot projects on circular design principles, such as design-for-disassembly. CIRCUIT was conceived from a systemic perspective with the goal of bridging policy, theory, and practice through a series of demonstration projects to be carried out by both public and private organisations, with the aim of scaling and replicating CE building practices in Europe. CIRCUIT has set targets to reduce carbon emissions, reduce virgin material consumption by 20% and to result in an overall cost savings of 15% in the participating cities. CIRCUIT was created with the belief that these goals can be achieved through the knowledge generated and disseminated from the planned 27 demonstration projects. They recognize that in order to achieve these targets the creation of new knowledge sharing structures, development of tools for doing so and creation of robust cross-disciplinary industry networks will be essential (ReLondon, 2020).

5.2 CE integration in the Danish building industry

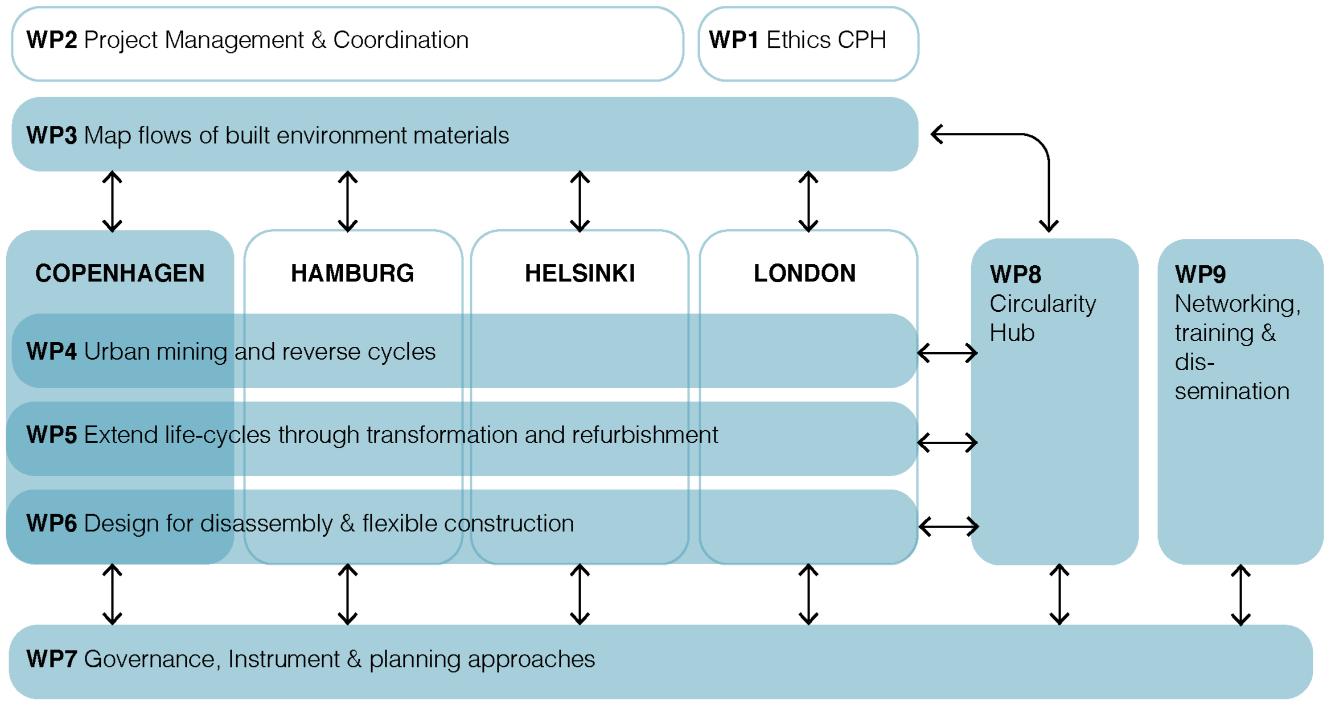
CIRCUIT was chosen as a case for study because it provides a window into the current state of integration of CE in the Danish building industry. Furthermore, CIRCUIT encapsulates the practical role of circular innovation projects in the sustainable transition of the building industry. As emphasized in Chapter 4, the benefits of CE are maximized when scaled to local, regional contexts, therefore this study was limited in scope, to focus on the Danish cases and partners, of whom are located in the Great Copenhagen area. This thesis study includes 5 of the 11 Danish partners organisations, pilot projects, and value chain actor roles. The organisations and their role in the CIRCUIT project have been described in **Figure 19**.

Rather than study the details of the individual demonstration projects this study focuses on identifying what key actors included in this study define as barriers (lock-ins) towards implementing CE in the Danish context. Although the formal organization of CIRCUIT is delineated by workpackage, the Danish conglomerate of participants has agreed to share findings and collaborate across workpackage with the aim of strengthening the regional network around CE goals. Through the interviews and workshops with the CIRCUIT partners, it was possible to compare theoretical findings discovered in Chapter 2 to those experienced in practice. The empirical findings of such discussion are presented across the three following Chapters 6, 7, & 8.

5.3 Characterizing the case

CIRCUIT is a useful context for gathering data on sustainable transition projects, in which a form of reflexive governance (Geels & Schot, 2007) is being enacted by the European Commission providing resources (financial, time, network) to CE demonstration projects. With the goal of learning from demonstration projects and disseminating those finds with the rest of Europe, CIRCUIT is creating the “protected space” for CE demonstration projects to exist (Brown & Vergragt 2008; Smith & Raven, 2012). This is an important step towards changing the narrative in the building industry in which it is being acknowledge by governing bodies that the existing linear development course is no longer suited to meet the challenges of our times. The EU is exercising a form of Strategic Niche Management (Schot & Geels, 2008) by financing the CIRCUIT demonstration projects. For CE to become a mainstream practice there needs to be a coordinated effort between niche innovation projects and regime actors, which CIRCUIT is enabling.

CIRCUIT is serving as a space for both new knowledge creation and new models for disseminating that information so it can reach beyond the spatial and temporal context of the demonstration projects. As described in Chapter 2.2, cross-disciplinary collaborations that results in higher order learning are essential to co-evolution of the niche and regime. While it’s too early in the CIRCUIT project to determine if such goals are achievable through this particular transition project – the on-going demonstration projects serve as a context for investigating opportunities and barriers to such a change.



WP1 & WP2 were organisational precursors to the demonstration projects. Similarly, WP8 & WP9 will be executed following the conclusion of the demonstration projects and are not subject to study in this report.

WP3 – A clear and consistent approach to data mapping, analysis, and management of such data is fundamental for realizing and harnessing the potential of the existing material stock. In order to optimize the material supply and demand relationship, material mapping and data banks are needed to ensure material re-use today, and in the future.

WP4 – In order to combat schematic about building material re-use, demonstration projects should focus on pre-demolition audits, adoptions needed in the selective demolition process, as well as the the reuse of materials or elements in new construction.

WP5 – With an effort to minimize waste and preserve the embodied energy of materials – emphasis should be placed on prolonging the life of building materials and elements. New knowledge is needed to better define, and establish best practices for sustainable transformation of the existing building stock.

WP6 – Enabling the key principles of designing for multiple life-cycles, demonstration projects should work to develop modular, adaptable, flexible building systems, with an aim of creating buildings that can easily be adapted to changing needs of building occupants.

WP7 – Acknowledging the influential governance role municipalities play in enabling or limiting circular transition of the building industry at a systems level, thorough analysis will be conducted of European, national, and local regulations, with the aim of creating future conditions which are more conducive to mainstream adoption of CE principles.

Figure 18

ORGANISATION	BUILDING INDUSTRY ACTOR ROLE	CIRCUIT WORKPACKAGE	DESCRIPTION OF CIRCULAR DEMONSTRATION PROJECTS
Danish Technical University (DTU) Civic Department for Civil Engineering	Research and educational institution	WP3, WP4, WP9	• Performing LCCs and LCAs on several selective demolition and material re-use projects vs traditional demolition projects • Creation of a “transformation potential” tool that will help access the value of existing building stock, to be tested in a social housing neighbourhood. • Developing a new sustainability framework for evaluating projects based on planetary boundaries. • Data generation for a material exchange platform
Enemærke og Petersen a/s (E&P)	Building Contractor with experience in both renovation and new building projects	WP4, WP5, WP6	• Turning waste flow into resources for product development, such as “Næste” • PHD projects looking into best practices for circular construction sites and circular tenders, respectively. • Testing new methods of material mapping and pre-demolition audits with the transformation of an existing school building, in which materials will be circulated for re-use. (Strategic partnerships - Trust)
J.Jensen r/s (JJ)	Demolition, selective demolition, material re-use, environmental screening	WP4	• Pilot project experimenting with new methods for removing toxic substances such as PCB from the existing building materials. • Working to circulate materials for re-use through the development of an “up-cycling center” in which re-sale, physical storage in a“material hotel” and application in new building projects are central. • Development of a tool which will make visible the economic potentials of material re-use
City of Copenhagen (KK)	Municipal Developer, Regional Lead of CIRCUIT project	WP1, WP2, WP3, WP4, WP6, WP7, WP9	• The municipality currently has 9 on-going transformation projects in which a diversity of circular principles are being used, such as preservation of the existing structure, material circulation for re-use and design for disassembly methods. • The collaborative development of flexible, moveable partition walls systems to be implemented in a school transformation project. •As regional lead of the CIRCUIT project, the municipality is working strategically to create lasting circular networks of Danish partners.
Lendager Group (LG)	Architecture, circular consultancy and material innovation	WP4, WP9	• A demonstration project that involves the selective demolition of a school building, of which materials are being circulated for re-use on the same sight in a circular kindergarten enabling various circular design principles, such as re-use of structural elements. • Development of pre-demolition audits for circular building projects in which qualitative and quantitative material studies are qualified within sustainable frameworks. • This thesis project will serve as part of Lendager Group’s contribution to CIRCUIT.

Figure 19

6

BARRIERS AND OPPORTUNITIES

6 Opportunities and Barriers

The literature on CE in the building industry identifies technical know-how and institutional conservatism as the primarily barriers towards implementing CE in the building industry. In the following sections we will hear from frontrunners who are working to implement circular innovation in the Danish context with the aim of answering the initial research question: “What are the opportunities and barriers towards implementing circular economy in the Danish building industry?

First, in section 6.1 empirical data generated in the first round of interviews is introduced and a comparison is made to the literature presented in Chapter 4. This data has been obtained and documented through methods described in the Research Design chapter. Secondly, in section 6.2 sense will be made of the data through the lens of the theoretical framework presented in Chapter 2.1. In this chapter the term “actors” will be used to describe those who contributed to the generation of empirical data in this study.

6.1 Insights from circular frontrunners

The first round of interviews was used to identify opportunities and barriers for CE in the Danish building industry. The interviews were conducted with an ambition to create a snapshot of how the building industry is today, how CE is situated within that context, and where reconfiguration is needed to allow a more hospitable context for CE implementation in the future. The interviews were an opportunity to hear directly from circular frontrunners who are experimenting in niche innovation spaces as to what is going on in practice, and to learn how current CE innovation projects “work around” the existing building industry lock-ins (Unruh, 2000, 2002).

The accumulative findings from 14 interviews are mapped and represented thematically in Figure 20. It is out of the scope of this study to dive deeply into the particulars of each innovation case or individual actor perspective, but rather create an overall impression of the findings. Detailed mapping of empirical data can be found in the Appendix #.

6.1.1. A pattern emerges

While sorting through the empirical data there was a general pattern in the first round of interviews. Such a pattern is abstracted in **Figure 20**. There was a general consensus among actors about what technical and institutional barriers stand in the way of mainstream adoption on CE in the building industry. Many of these barriers, such as lack of building material information, building codes which are not hospitable to circular building practices, or economic mechanisms which do not align with the long-term incentives of CE, echo the barriers identified in the Literature Review – Chapter 4. Actors were quick to point out such obstacles but didn’t dwell on these topics. Rather actors were keen to discuss barriers of the behavioral kind such a need for new “circular thinking” to be reflected in project frameworks and processes. The desire to discuss such qualitative aspects stands in contrasts to the literature on CE in the building industry, which is dominated by analytical studies where the primarily focus is the technical aspects of CE. This finding also stands in contrast to the highly technocratic sustainable transition literature.

Observing this phenomenon was a key turning point in the study. Once it was identified the actors were mostly concerned with how they work together with others, how new knowledge is generated and documented and how new processes are needed, that better reflect the circular nature of innovation projects the research pivoted to better understand what defines and impacts behavioral lock-in. In the following subsections, themes identified throughout the mapping of empirical data will be elaborated on.

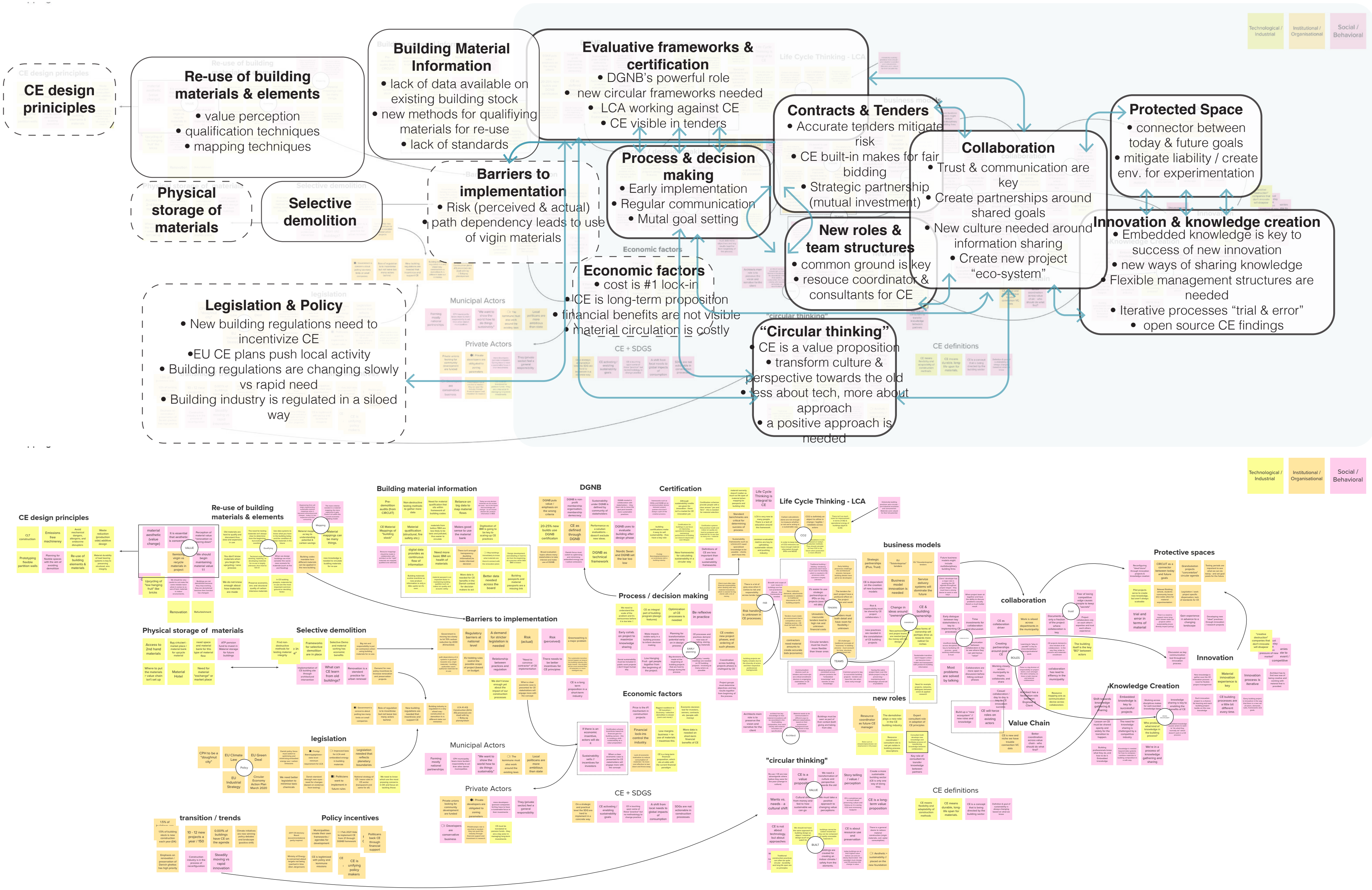


Figure 20

a) Emprical data mapping simplified b) Emprical data mapping original

6.1.2 Making a case for circularity

The actors included in this study are all involved with circularity projects. Depending on their role in the building industry, they have very different reasons for engaging with CE projects. Most actors are engaging with CE because they seek to gain experience in advance to a changing industry. In many cases they fear "creative destruction" in which companies that don't innovate will disappear. For example, *"Developers can see that in the near future there is going to be a lot of higher demands for sustainability. So, they want to have some experience in advance to be ready to adapt to those new changes"* (Circular Project Lead)

As municipal actors, the City of Copenhagen would like to *"Show the world how to work on sustain-ability"* (Municipal Lead Consultant) thus pursue CE demonstration projects as part of this cause (Runge, 2020).

Many actors find that CE is spoken about, but isn't being applied at the rate which is needed:
"There's a willingness to do it in the spoken word, but in action, there's still a long way to go" (Municipal PM, Sustainable Construction & Reuse). While others find that circularity is useful concept for mobilizing the industry, but not the sole answer to sustainable transition: *"I'm very skeptical about the circularity as the circular economy, as a valuable framework. I think there's a lot of points and benefits that get lost if you only look at circularity"* (Technical Director). Buildings are complex and have a long lifespan, whereas many of the CE principles are defined at material level. It's very important to design the building from a holistic perspective – otherwise it's very hard to reach sustainability targets - which is the end, is the goal of CE.

Others feel that while CE is presented as a new, many of the principles are part of building tradition:

"I think if you go back in time a hundred years, every building was a circular building. All the mate-rials and all the practices were based on principles that make it possible to change the buildings over time, but also to actually demolish and reuse every bit of material in the buildings, and that changed in less than 200 years ago with the start of the industrial processes. We went further and further away from this circularity in the building industry" (Technical Director).

When asked what the future looks like for the Danish building industry, many were uncertain:
"Will we be totally circular? …I'm not sure about that… but I think the main pressure will have to come from the government, politicians on legislation, restrictions on the construction industry. We have seen in the last 10 years, it hasn't moved at all (construction industry), even though we have these innovative companies as Lendager, who show that it can actually be done, and it is economically feasible. The construction industry is so conservative that they don't want to have any uncertainties. It's easier to do it the same way as we always have done." (PhD Circular Construction)

6.1.3 Legislation and Policy

When speaking to actors, often legislation and policy were identified as critical aspects to changing the building industry. Many pointed out that EU policies such as the EU Industrial Strategy, EU Climate Law, EU Green Deal and the EU Circular Economy Plan as paving the way for the Danish national governments to implementing CE policy. Evidence of this change in values is in the Danish context is national elections.

"What we saw in the election June 2019 was a major shift in attitude towards climate change. Until then, you could not win an election on 'We want solar...We want ambitious climate change initiatives.' So, a change in the way we perceive the globe, as not just an abundance of materials to fulfil our needs, but something we have to cherish and something we have to protect. Could you win an election on that? That would be magic." (Municipal PM, Urban Renewal)

"Voters, they vote for politicians who push the agenda on circularity and down to our own col-leagues, who are the developers. So, it's the voters. The people are keen on sustainability and getting the numbers down on the CO2" (Municipal PM, Sustainable Construction & Reuse) CE is perceived as a mechanism by which carbon reduction targets can be met.

Regardless of this change in values, it was identified by actors that the current building code legisla-tion and policy give little incentive to apply CE building principles, making it hard to complete with linear methods of construction. Denmark is currently experiencing a slow reconfiguration period of building regulations. New policies such as the Frivilligt Bæredygtighedsklasse (Volunteer Sustainabil-ity Class) are paving the way for CE principles, to become an integral parts of building codes.

Danish actors note that there isn't too much room for improvement in terms of indoor air quality and operational energy of buildings – thus it's time to shift focus towards a life cycle perspective. To do so, danish building legislation must shift focus and deal with the "Contradiction of using a lot of ma-terials actually to achieve this indoor comfort and the energy efficiency. So, there is this double as-pect. We are very good in efficiency, but the embedded CO2 in in these three-layer windows isolation and concrete" (Housing and Planning Clerk) have a very large impact. Here, the relationships be-tween institutional factors and behavior of building industry actors are made quite visible.

In spring 2021, an effort to reduce construction related carbon emissions by 70% in the year 2030, new restrictions were put were put in place by Denmark's National Strategy for Sustainable Construction in which carbon limits will be placed on new buildings. Although this is a step in the right direction, the bar is set very low. Beginning in 2023 buildings exceeding 1000m2 will have CO2e limits corresponding to 12kg CO23/m2/year, with a voluntary sustainability class of 8kg COe/m2/year. A study has shown that 90% of buildings in Denmark already meet the demands set forth by this regulation. While the plan is to incrementally make the restrictions stronger, it won't be until 2030 before the regulation will have the desired consequence of buildings meeting 7.5kg CO2e/m2/year (Passive House Plus, 2021). An overwhelming consensus by actors that strong restrictions are needed, much sooner.

"The number of actors giving a positive feedback for this kind of law is growing. They want to have more rules in the construction sector related to circular construction and sustainability. But the only thing is, it has to be transparent, and it has to be the same for all...but these laws are not as ambitious as they could be" (Municipal PM, Sustainable Construction & Reuse). Financial mechanisms, that deal with the issues of fairness and competition are highly impacted by legislation.

When hearing from the actors who work within building regulation, they express concerns about the speed at which changes are happening as well:
"We need to make sure that the industry is ready to make those calculations (LCA) in the right way and use the tool to actually optimize their buildings. We need to make sure not to put criteria, which create some imbalance in the market, so we need to make sure that all the producers can catch up with developing their products in a more sustainable way…So for us, it's all about creating this balance of not being unambitious, but also not being too ambitious... It's all about finding balance and making sure that everyone can catch-up, but also that everyone does not continue with business as usual" (Housing and Planning Clerk).

Beyond building codes, another barrier mentioned by actors is that other policies that deal with different aspects with the built environment, such as municipal zoning requirements and waste management are all handled by different ministries. This siloed approach to policy making, in which different building project phases are controlled by different local or state-run ministries, makes for very slow improvements in the overall footprint of building construction. For example, municipal developers can creatively use zoning rules to incentivize the re-use of building exteriors in an urban area, but they cannot set demands for the amount of material re-use in a project (Municipal PM, Sustainable Construction & Reuse; Housing and Planning Clerk). The complexity of building projects means there are many moving parts and there is not one fixed solution.

6.1.4 Building materials for re-use

In this section, many of the issues presented by Danish actors echo the literature presented in Chapter 4.1.2. Throughout the interviews actors were quick to detail the limitations of our current technical systems and supporting infrastructures. Most actors are applying CE building principles through transformation of building materials for re-use and building transformation projects and see great potential in using what we already have:
"It's actually where we think we can have a huge impact. If you can inform about this transformation potential in the early phases. You can see this building, for example, has high potential for transformation to a school, but also for an office. I think it's important to shift this, the thinking about how can also address flexibility of the current building stock." (PhD Circular Construction).

In order for this perception to be adapted by mainstream actors, there needs to be a change in mindset and values towards material re-use (Beim et al., 2019). Furthermore, there is a need for "consensus" about what is considered valuable resource, and what is considered waste (Malmqvist et al., 2020). Mainstream "consensus" is most likely to be reached through the transformation of building codes.

Danish actors experience a frustration over the limited data available on the existing building stock. There simply isn't enough building material information to make informed decisions when it comes to material re-use. There is a need for institutions like Dansk Standard to develop standardized methods of testing materials for re-use. Such standardizations will reduce the time spent on material qualification, financial expenditure, and perceived risk associated with material re-use. (Circular Consultant).
"We need the technology to be able to qualify this material so that it can be re-used and prove it has the same quality as new materials…" There is a need to, "remove some restrictions which makes it difficult to re-use, but in the same way to make reuse safe and responsible." (Housing and Planning Clerk)

Issues of material health and quality are essential to the holistic design of sustainable buildings and cannot be soon overlooked (CTO Material Passports). *"I don't think that it is a problem when we say, 'We don't want you to make the same mistake one more time' and include these materials in our new building if they are actually in a compromised kind of toxic chemical"* (Technical Director)

Furthermore, once quality of materials is addressed there are also issues of availability:
"Are there enough materials, and in a good enough quality? I'm not sure about that. So that's going to be the main problem right now. We have a lot of material with a

lot of dangerous substance in PCB asbestos. So, actually a huge part of the material mass is contaminated. So, there is a limit to how much (material) can be applied to new design and how much (material) we have to produce new in sustainable ways." (Municipal Lead Consultant). As referred to in Chapter 4.1.3, in order to resolve such issues accurate data on the existing building stock is needed (Bertelsen et al., 2020).

The current institutionalized metrics for evaluating the sustainability potentials of buildings, such as LCAbyg "do not consider material reuse and design for disassembly in the calculations. So right now, we need a lot of data and research before we can say for sure that this is the best way to go forward." (Municipal PM, Sustainable Construction & Reuse). CIRCUIT demonstration projects are one avenue for generating the needed data to make informed decisions in the future. LCAbyg is an institutionally accepted metric for measuring sustainability outcomes of building projects. The results of which affect behavior, economic mechanisms and policy. At the moment, LCAbyg does not make visible the benefits of CE building principles. Until such benefits are visible, there is little incentive to implement CE.

While most actors work with re-use of the existing building stock, there is still a lot of uncertainty about the most appropriate ways to do so. As such, there is a growing demand for new evaluative frameworks and certifications which integrate CE into their metrics.

6.1.5 Evaluative frameworks and certifications

Current institutionalized frameworks, such as contract and tenders are reflective traditional processes and a deep-rooted eversion to risk, limiting the experimentation potential within typical building projects. Such frameworks drive process, behavior, the way in which sustainability is defined. New contracts, demands, and attachments are needed in addition to tradition documents in CE building projects that deal with both real and perceived risks associated with material re-use (Municipal CE Lead).

Some actors feel CE hast potential be implemented within the current confines of traditional contracts such as Strategic Partnerships, EU totalenteprise, EU Hoventerprise, so long as circular elements are integrated and defined early.

"Tenders must create an environment that makes for competitive bidding – meaning CE must be built in. Tenders should happen as early as possible in the project, because once implemented – it's hard to work around them. This challenges the architectural process, which typically happens before bidding and tendering" (PhD Circular Tenders).

Bonomami (2020) suggests early interaction between collaborators, for strong network building and business models that reflect CE principles. CE challenges traditional concepts of "economy" in bidding process, must account for more time, structure, collaboration, experimentation, which is hard to do in an accurate way when there isn't enough building material information (Municipal CE Lead). In addition, sustainable certification schemes play a major role in the implementation and standardization of CE. All of such frameworks structure the way building projects are conceived and the processes by which they are executed.

Many actors identified DGNB as an important framework for ensuring sustainability in the Danish building industry. Today, the DGNB framework is used in 20-25% of all new building projects (Technical Manager) and the City of Copenhagen has committed to certify all building projects through DGNB from 2022 (Municipal CE Lead). At the moment DGNB frameworks give bonus credits for implementation of CE principles but can't yet demand them – as there is still a lack of knowledge, clarity of definition, and need for further innovation (Green Building Council Denmark, 2019; Technical Manager). DGNB sees their role as one that is meant to keep pushing the industry towards increased sustainability – and CE is a part of this, but not the entire solution:

"So, the lifecycle perspective has been there from the beginning and it's the basis for the holistic thinking in DGNB. So of course, CE fits very well into our general framework. It's just phrased or named in a new way, now using 'CE' whereas before we phrased this as 'lifecycle perspective.' So, there's nothing new there, actually. Not just thinking here and now, but in the long run…It's a circular perspective that that we have as a backbone for the criteria in general" (Technical Manager).

Common evaluative frameworks such as LCAbyg which work to create benchmarks play a critical role in contextualizing success of each project and comparing different building methods to each other. *"That is the main point of certification. That is to say, well, we have this common evaluation method and rating. And because of that, it is possible for us to say something is more or less sustainable"* (Technical Director). The perceived "level" of a buildings sustainability is becoming both a market mechanism and a policy instrument. Investors, developers, and politicians are waking up to the fact that the general public would like an increased level of sustainability, and residents for example are willing to pay more in rent if it means their environmental footprint is smaller. Therefore, how we measure sustainability matters, and should reflect total life cycle of a building (Municipal PM, Urban Renewal; Circular Project Lead: Bertelsen et al., 2020). *"CO2 is definitely an object to utilize in change"* (Circular Consultant).

New legislation, such as Frivilligt Bæredygtighedsklasse require specialized knowledge on LCA methods to be useable, which only a small percentage of industry professional are equip with; therefore, many investors and developers rely on systems like DGNB to ensure sustainability of their building projects. *"It is quite complicated if you never worked with before. People don't know what is actually 'okay'"* (Housing and Planning Clerk) therefore more data which reflects life cycle thinking is needed, to create stronger frameworks, as are consultants who can facilitate CE building processes. The Danish building is currently experiencing a slow reconfiguration of the technical and institutional lock-ins. The knowledge of many actors is needed to key pushing sustainable transition, thus creating networks and new methods for collaboration is key.

6.1.6 Collaboration for knowledge creation and innovation

There is a recognized need for new business models, contracts and tenders which are more hospitable to circular collaboration. Furthermore, there is a need to create industry-wide partnerships around the goal of CE – which many actors feel is the potential of CIRCUIT. Actors must be willing to experiment with new frameworks, which better align with CE goals and better enhance communication: *"I think the key factor is time… We think that systems can do everything. And the fact is, that we have to talk. You have to talk together to make things and after you have to write them in your tenders"* (Municipal CE Lead). People must talk together. The solution to CE is of a social nature.

Actors need to contribute their knowledge at different phases of the project – meaning there is a need for flexibility in tradition role structures, as well as the creation of entirely new roles to facilitate CE building projects. For example, the role of demolition companies is changing with CE. Their expertise is needed much earlier in selective demolition projects, which requires them to interface with project collaborators and planning frameworks in a new way (Demolition, Sustainable Manager). This will take thoughtful planning, value chain coordination and collaborative boundary work (Bos-de Vos et al., 2019).

It is recognized by actors that early dialogue between all stakeholders, both internal (project conglomerate) and external (consultants and specialists) are needed to implement CE from the beginning of the process. Many actors find that informal discussion and sharing of knowledge is allowing their current CE projects to prosper. Both official and informal communication across the building value chain is essential to creating new practices and behaviors for CE:

"When we talk about connecting dots and value chain, there is an opportunity through CE, to collaborate across different offices within the municipality, which gives us the power to develop a stronger value chain for material flows...Traditionally, the different departments in the municipality, we are as any other large organization, are siloed…We are very good at what kids in kindergarten do 'play in parallel'... They can sit next to each other and they can play in parallel, but they do not play together. That comes when they start schooling. And large organizations like ours are quite efficient in playing parallel." (Municipal PM, Urban Renewal)

"Let's go for the low-hanging fruit, and just get people together from the beginning" (Circular Consultant)

CE projects demand a new mindset of all collaborations – in the way they relate to process and materials. Aligning goals and visions is key, as is knowing the process will be different than expected. Each innovation project challenges traditional process, and frameworks should be agile and reflective of the innovation process. The innovation projects result in new knowledge each time: *"I am convinced, next time we will do it entirely different, because we know more."* (Architect) which must be transferred from one project to the next.

Project collaborators rely on each other's expertise and trust such embedded knowledge. Working across disciplines makes for well-rounded knowledge base. Knowledge sharing is challenged by the competitive, low-margin industry – although almost all actors feel lessons from CE pilot projects must be open-sourced for transition to happen at an appropriate rate: *"The fact that I have actually connected people has been important in this project…If you don't use resources, human resources on connecting people and working on these things, then nothing will ever happen."* (Municipal Circular Lead).

Most actors note: *"We simply do not know enough yet"* (Circular Consultant) – thus we need more resources for innovation projects. Transition projects as CIRCUIT, create space for experimentation and knowledge generation that is much needed.

"I think we have to support a shift and an inflow of knowledge and we have to be patient and see what comes out of it. The whole focus with all of those initiatives (innovation projects) is how to scale this circular economy, because we can easily support interesting demonstration projects that are a lot more expensive than the market could do themselves. This is the way to find new business models" (Circular Project Lead)

Actors situated as project managers in CE innovation projects must work to translate CE principles to their colleagues who have yet to engage in circularity discourse. CE is still in infancy stages, meaning there is a need for tools and frameworks which help mobilize and coordinate actors around CE processes:

“My immense task right now is to mobilize this internal framework to make kind of a system that can deliver all these materials. In that sense, I kind of I need tools to kind of disrupt the dialogue with all these building sites. I need to understand how I can disrupt their traditional processes and say, hey, I need these materials. I need to be able to support a local project manager, who is my colleague and how he will take a dialogue with his subcontractors on the demolition and all this. So, I need a kind of process understanding, I need a kind of a cultural mindset with my colleagues, I need to kind of have supportive tools. Yes. To strengthen their dialogue, make it easier for them. Yeah. I need a new infrastructure of collaboration partners.” (Contractor, Head of Sustainability)

Furthermore, actors will need to display a fair amount of resource fitness (Cheng et al., 2008) and adaptive capacity (Gluch et al., 2020) in order to achieve circular goals:
“I think in the early stages of the circular economy and circular construction, we still need the time aspect because all the routines and the framework for circular economy isn’t set yet. So, we need to develop these, and it will take time.” (Municipal PM, Sustainable Construction & Reuse)

6.2 Making sense of the data

Reflexive governance (Geels & Schot, 2007) is defined as a way of governing or managing that prioritizes “learning, interaction, integration and experimentation on the level of society” (Loorbach, 2010, p.164) for sustainable transition. At the moment the there is evidence of such reflexivity on the European, National and Local levels. The EU (European Union, 2020) is pushing a CE agenda and funding of projects for circular innovation through Horizon 2020, such as CIRCUIT. On a national level of new policies such as the Frivilligt Bæredygtighedsklasse have begun with a two-year, learning period. In this period, much needed data is being harvested from voluntarily projects, so the government can implement new restrictions that both push the industry towards sustainability without leaving too many market actors behind (Ministry of Environment and Food, 2018). On a local level, the City of Copenhagen is finding CE to be unifying force across municipal departments and plan to expand their portfolio of CE demonstrations by 10 projects each year. Furthermore, municipal developers work in a semi-protected space and are working to pave the way for the rest of the industry (Runge, 2020). All of these CE efforts are framed within the discourse of climate goals, mainly a need to hit CO2 reduction targets by the year 2030.

It is clear, that although the lock-in of linear building principles are mutual reinforcing each other, Denmark is experiencing a period of reconfiguration. At the moment, the CE knowledge and understanding (data, new methods of circulating materials, certifications, human networks) are the missing link (**Figure 21**). National level institutional lock-ins such as climate policy and building codes, shape and define municipal policy, such as waste-handling. Municipal waste policies impact the rates and methods used in the processing of building materials. At the moment, it is much easier to process waste for down-cycling than preserve materials and store them in material banks for later use. This results in situations of technological lock-in where there is a lack of standardized knowledge or processes needed to a) test building materials for their quality (strength, safety, carbon) and b) there isn’t adequate data on material quantity or location. Without this data, materials for re-use lack safety data sheets and certifications, which impacts the actual and perceived risks of incorporating them into construction derivatives, like contracts and tenders. Such risk, effect behavior and practices. While individual value perception is changing and many building actors see great potential in preserving material worth of the existing building stock, construction management frameworks which dominate the industry have little flexibility when it comes to factors of time and economy. Sustainable transition projects such as CIRCUIT are creating protected spaces (Smith & Raven, 2012) for innovation where the critical knowledge we need to overcome the aforementioned lock-ins is currently being generated through demonstration projects.

CIRCUIT demonstration projects straddle the line between niche and regime socio-technical levels. While CIRCUIT provides a protected space in which financial risk is mitigated by EU funding – all projects are being implemented within a context primarily defined by linear thinking. This will hopefully create a condition for co-evolution of the niche and regime, in which the innovations are more likely to diffuse and be adopted by mainstream actors outside of the demonstration projects. (Brown & Vergragt, 2008; Seto et al., 2016) This understanding is reflected in the ambitions set for by CIRCUIT in which there is a recognized need for both technical innovation and “Circularity Hubs” for networfication of Danish building industry actors (ReLondon, 2020). It’s important to set focus on how to best create new networks – essentially a social and behavioral task.

Unruh (2002) defines six events that can lead to overcoming lock-in: crisis in technology, new regulation, technological breakthrough, changes in values, development of niche markets, and scientific results. CIRCUIT demonstration projects are working within these different areas to reconfiguring the building industry for sustainable transition. While there is no immediate crisis in existing technologies – continuing on the current development path, will result in issues such as resource depletion and extreme weather (Röckstrom,

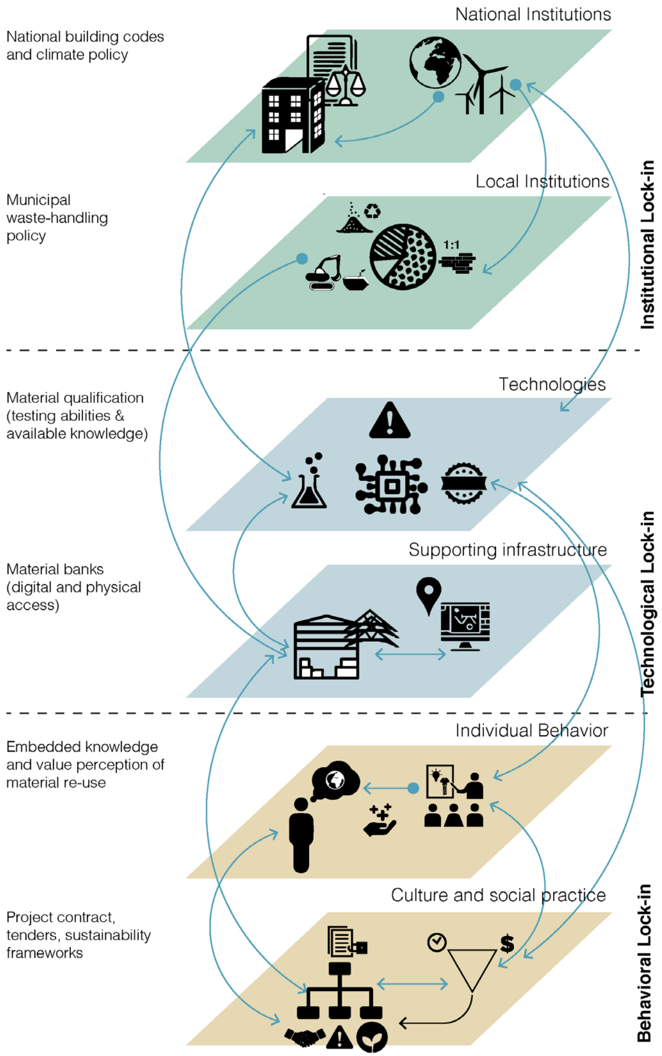


Figure 21
Mutually re-enforced lock-ins. (Inspire by Seto et al., 2016)

2015), which will challenge building technologies of today. Actors involved in this study are aware of this pressing issue and recognize the urgency need to push for new legislation but are not waiting for legislation to "catch-up" to the need for rapid innovation. The actors demonstrate a change in values, in which materials should be preserved at a high value and are working to create scientific results that will support circular transition of the building industry. Each demonstration project on its' own isn't so powerful, but Schot and Geels (2008) state that as the niches "branch, pile up, and contribute to changes in behavior" (p. 548) through the case-comparison, knowledge sharing, and circular network creation efforts of CIRCUIT - there is a chance for having a lasting impact on regime "behavior, practices and routines" (p.548).

6.3 Moving forward

Through discussion with actors' barriers to implementing CE in the Danish building industry were identified. While many of the barriers identified are of the technical and institutional nature, many of issues discussed focused on the social and behavioral barriers towards implementation. Many of the needed technical and institutional developments needed are dependent on the successful implementation of data generating circular demonstration projects, which current have both social and political backing. Such demonstration projects are highly dependent on the willingness of actors to act, based on a new set of circular values, engage in experimentation, and exchange information in a highly collaborative setting. As such, circular building projects are defined by their cross-disciplinary, inter-organizational approach to problem solving. According to the literature on CE in the building industry there is a need for organizational tools to facilitate CE building processes, that work to coordinate interaction between actors. Through discussion with Danish, circular frontrunners this finding is corroborated.

Overarching frameworks such as contracts and tenders currently used to organize the building projects reflect linear thinking. Most actors are comfortable working within these boundaries (for the time being) and don't feel changing such frameworks is immediately possible. There is, however, room to shape new processes within the niche innovation projects, that are happening parallel to building projects. Most actors are currently working to implement CE within building transformation projects, in which their goal is to preservation of the existing building-stock. There is a need to create and document knowledge about how to best circulate building materials for re-use, a process highly dependent on collaboration and knowledge exchange between actors – aspects that are highly social and behavioral in nature.

In order to understand such social and behavioral aspects of collaboration better the author dove into new theoretical concepts within the fields of organizational and innovation studies. This branching out as necessary because the sustainable transition literature has a very limited focus on behavior aspects of socio-technical lock-in. The "new" theoretical concepts are presented in Theoretical Findings - Chapter 2.2. In addition to the topic of collaboration, the author looked into of traditional and sustainable project management frameworks used in the construction industry, of which findings are documented in the Literature Review – Chapter 4.2. Both explorations were an attempt to better understand the collaboration frameworks currently lock-in in the building industry, and how to work around such conditions for optimal conditions. The result of this exploration is presented in the following Chapter.

7

CHALLENGING ASSUMPTIONS

7 Challenging Assumptions

This chapter is written in two distinct sections which reflect the process by which this study was conducted Figure 22. In the first section of this Chapter 7.1 the aim is to present the finds from the data Assumption Game, of which was obtained and documented through methods described in the Research Design chapter. In the second section of this Chapter 7.2, sense will be made of the data described in the previous section. The frameworks articulated in Chapter 2.2 – Theoretical Frameworks will be used to structure this analysis. The findings from this chapter culminate in a specification for a Collaboration Tool which is detailed in the Design Space – Chapter 8.

In this chapter the aim is to answer the secondary research questions:
"What new methods of collaboration are necessary in circular building projects?" and ***"What collaboration tools are needed to facilitate such an interaction?"***

7.1 The Assumption Game

The process by which the Assumption Game was developed and played is articulated in the Research Design - Chapter 3. The Assumption Game is the result of accumulative knowledge generated on throughout the project, with particular focus on theoretical findings presented in Chapter 2.2 and the literature review presented in Chapter 4.2. Furthermore, insights from 6.1 suggest the importance of collaboration. The intersecting of theme of "collaboration" investigated throughout this process is pictured in **Figure 22**.

The results of the empirical data generated in the Assumption Game are presented in Figure 22. The "Assumption Cards" are organized in the following themes of "Collaboration", "Innovation" and "CE Processes." The text written on each card is written in the left-hand column, where-as the placement of each card is represented by dots place in the columns to the right: "Yes, definitely," "Kind of, sort of, maybe," "No, not really," and "I'm not sure." Each dot represents a single player. Assumptions highlighted represent outliers that either a) stand in contrast to assumptions generated from theoretical findings, b) stand in contrast to assumptions generated from literature review and industry discourse, or c) where the six players had diverging perspectives. These points of interest will be elaborated on in the following subsections. The cards where there was strong consensus among actors were added to the specification for the Collaboration Cool, that will be presented in Chapter 8.

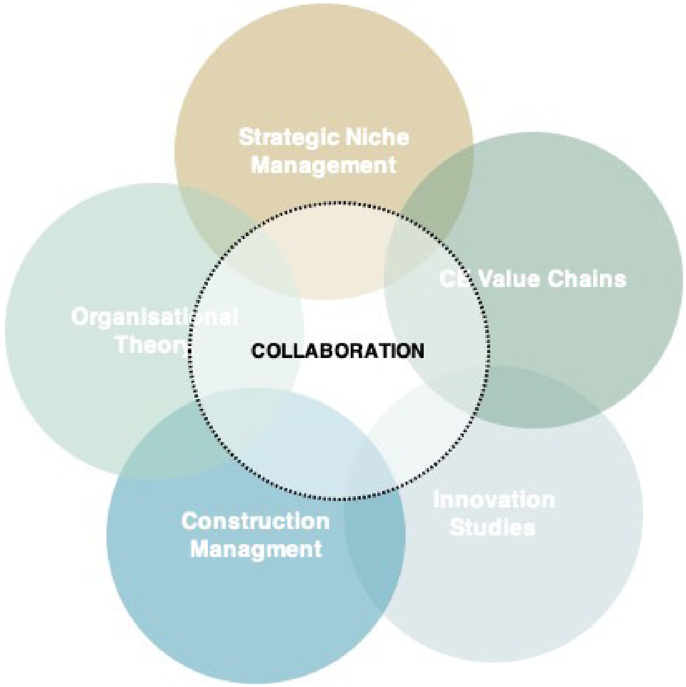


Figure 22
Mutually re-enforced lock-ins. (Inspire by Seto et al., 2016)

Assumption Cards	Yes, definitely	Kind of, sort of, maybe	No, not really	I'm not sure
Collaboration				
Trust is a big factor in collaboration	●●●●●●			
It can be hard to sustain interaction between collaborators	●●●●●	●		
We typically enter into collaborative processes to gain new knowledge.	●	●●●●●		
Willingness to try new things is an important factor when choosing a collaboration partner.	●●●●●●			
It's important for to have agency in a collaboration process.	●●●●	●●		
Creating long-term professional relationships is an important benefit of collaboration.	●●●●	●●		
Having shared goals is an important factor in collaboration.	●●●●●	●		
Collaboration projects demand designated leadership roles.	●●●●●	●		
We consider resource fitness (time) an important attribute of a collaborator.	●●●●	●●		
Most problems are solved through discussion with collaborators.	●●●	●●●		
Collaborators must adapt their traditional practices in circular building projects.	●●●●	●●		
Building industry professionals are used to collaboration.	●●●●	●	●	
Risk is a big factor in collaboration projects.	●●●	●●	●	
We feel vulnerable in a collaborative setting.		●●	●●●●	

Figure 23
"Collaboration card" results

7.1.1 Collaboration

The "collaboration cards" present assumptions identified as key elements of successful collaborations across the literature covered in this study (**Figure 23**).

When presented the "***We typically enter into collaborative process to gain new knowledge***" and "***Building industry professionals are used to collaboration***" there was an interesting dichotomy. It was emphasized by the actors that almost all building industry projects, whether full-scale buildings or material innovations involve some amount of collaboration. Often times, actors collaborate because it is necessary. They remarked that while the generation of new knowledge is often a bonus of collaboration, it's not often the end goal. They remarked that in the context of CE innovation projects, more emphasis is placed on the generation of new knowledge but that there isn't always enough time prioritized to documenting the knowledge or transferring it for application outside of the particular project. So yes, collaboration is a staple of the industry – and actors are quite "used to it" but they unanimously remarked "We aren't actually that good at it" especially when challenged by new processes. They feel that CE challenges the traditional collaboration roles, and they see a room for improvement in process work, communication, and relationship building between organisations. Thus, there is a recognized need for some kind of boundary object (Star, 2010) that sits between actors to help facilitate or steer project development. Such an object should also work to sustain interaction throughout the course of a project.

When asked if "*Risk is a big factor in collaboration*" the general answer was that it really depends on the situation, the type of partnership, the amount of responsibility their organization takes on in the collaboration, and the types of contracts and tenders (project frameworks). They generally felt that if project frameworks are well-written and understood by all parties they rarely felt "**vulnerable in a collaborative setting**." When vulnerability is mitigated, essential social elements of trust and individual agency are heightened.

7.1.2 Innovation

The "innovation cards" present assumptions identified as key criteria of innovation projects across the literature included in this study (**Figure 24**).

The actors were split on whether or not "***New frameworks are need for CE innovation projects.***" Most felt that existing contracts, tenders, and sustainability frameworks are sufficient for directing the overall structure of CE building projects. As mentioned, articulated in **Figure 19**, most actors included in this study implement CE building principles at the building material scale. Meaning, they could use organizational tools which facilitate the circulation of building materials for re-use and can "***serve as a common language between partners***", but such processes can exist within the traditional building process. Those who felt strongly that circular frameworks are needed, are working directly with development of such devices. Furthermore, the actors felt that "***understanding the big picture***" is relative to the amount of responsibility and agency they have within a project. For example, if they are acting as an expert consultant to supply a very specific piece of data, the big picture isn't important – whereas when sitting as project manager "***understanding the big picture***" is key.

When asked to reflect on "***Sense of urgency as a key to innovation success***" many felt this was true, given the sense of urgency was for the "right reasons." They remarked that the building industry is beginning to transition because of the urgency presented by climate change and virgin material depletion. They reflected that

Assumption Cards	Yes, definitely	Kind of, sort of, maybe	No, not really	I'm not sure
Innovation				
New frameworks are needed for CE innovation projects.	●●●	●●●		
We are dependent on the knowledge of our collaborators in innovation settings.	●●●●	●●		
Projects such as CIRCUIT serve an important role the creation of new circular innovations.	●●●	●●●		
Learnings from circular innovation projects should be open-sourced.	●●●●	●	●	
Each collaborator should have access to new knowledge generated in the innovation process.	●●●●●●			
Experimentation and "learning by doing" is important to innovation processes	●●●●●●			
Information tends to get lost between different phases of an innovation project.	●●●●●			●
A sense of urgency is key to innovation success.	●●●	●●●		
Collaboration tools should serve as a common language between partners.	●●●	●●●		
Understanding the big picture is important to fulfilling my role in an innovation project.	●●●	●●	●	
Collaboration tools should be agile in an innovation setting.	●●●	●●	●	
Protected, innovation spaces are important to mitigating risk.	●●●	●	●●	

Figure 24
"Innovation card" results

those aware of the problems whose values are aligned with sustainability are acting to innovate – and this is a good thing, where-as a sense of urgency incentivized by purely economic gain, might end in non-sustainable innovations. Therefore, organizing around sustainable values as well as shared visions and goals is one of the keys to collaboration.

When asked to reflect on the role of "***Protected, innovations spaces***" such as CIRCUIT, in the "***creation of new circular innovations***" and "***mitigating risk***" they in a best-case scenario, the answer is yes to both of those assumptions but often it depends. For example, while CIRCUIT is only partially funded by the EU – meaning all demonstration projects must also result in some kind of economic gain and satisfy "real world" clients – so they aren't as free to experiment as in fully-funded projects. They also reflected that the organization of the projects matters, and the scale and project structures of CIRCUIT do not create optimal conditions for innovation. The scale and overall structure of the project isn't always conducive to project level efficiency.

7.1.3 Circular Processes

The "circular process" cards present assumptions identified as keys to the implementation of CE in the building industry and are an accumulation of the entire study. These cards allowed the actors to react to the overall discussion and findings from the First Round - Interviews as well as discourse presented in theory and industry reports (**Figure 25**).

When asked to reflect on whether or not "CE building process cannot happen without need methods of collaboration" the discussion was akin to surrounding the topic of "New frameworks for CE innovation." Some felt that yes, new methods for collaboration are essential to maximizing the potential of CE, such as new business models, partnerships around projects and even ownership models of material elements and buildings. Those who answered yes, have managerial or consultant roles, so are often tasked with steering collaboration processes. Others felt that CE building processes are happening today within the confines of linear collaboration methods and only small changes are needed to speed up the pace at which CE is adopted. Unanimously, they all brought up the fact that integrating and articulating circular goals in project contracts and tenders will have a bigger influence, than by modifying the collaboration methods by which those results can be achieved.

When asked if the "the move towards CE is an extension of sustainable transition" the answers were quite varied. This is a reflection on the diversity of definitions of sustainable transition, as well as a lack of consensus about how CE should be defined. This card provoked a lot of discussion about the definition of such terms.

When asked to reflect on assumptions about why actors work with CE such as "We participate in CE innovation projects to obtain competitive advantage" and "Mainstream building industry actors will only implement CE when it is required by building regulations" the reflections were diverging. For example, when asked about competitive advantage as a driving factor for engaging with CE, private actors said yes, whereas public actors remarked that their engagement with CE was more or less evidence of political will and a value-change among voting constituents. When asked about mainstream adoption they reflect that yes, building regulations will get everyone on board, but if economic incentives are presented in a convincing way beforehand, mainstream adoption is also likely. At the moment, CE is being touted as the economic solution to sustainability, but there still isn't proof, nor consensus about whether or not "CE building solutions are economically viable." At the moment, the mainstream industry is dominated by short-term results, thus the long-term economic

Assumption Cards	Yes, definitely	Kind of, sort of, maybe	No, not really	I'm not sure
Circular Processes				
CE challenges traditional design processes.	●●●	●●●		
CE building process cannot happen without new methods of collaboration.	●●	●●●	●	
Circular goals must be integrated from the earliest phases of design.	●●●●●●			
The success of CE is dependent on the adoption of a new set of values.	●●●●●	●		
We participate in CE innovation projects to obtain competitive advantage.	●●	●	●●●	
The move towards CE is an extension of sustainable transition.	●●●●	●	●	
Regulatory entities should be more supportive of CE.	●●●●●	●		
We are ready for new types of CE frameworks, such as contracts and tenders.	●●●●	●		●
Coordination across the value chain is essential to CE.	●●●●●●			
Mainstream building industry professionals will only implement CE when it is required by building regulation.	●●●	●●	●	
Technology is the main barrier to mainstream adoption of CE.		●●	●●●●	
CE building solutions are economically viable.		●●●	●●●	

Figure 25
"Innovation card" results

benefits of CE are misaligned with the dominant financial mechanisms.

Finally, most of the actors did not agree that "***Technology is the main barrier to mainstream adoption of CE***" but rather that a change of values, processes, and a need for knowledge generation are more pressing barriers to overcome:
"I think it's the difficulty or unwillingness to change business as usual, it's not technology, it's like just setting a certain path" (Municipal PM, Sustainable Construction & Reuse)

7.2 Making sense of the data

In the literature on CE in the building industry, across the socio-technical literature on niche innovation demonstration projects and in discourse with actively actors working in these spaces - there is consensus that there is a need for new behaviors and processes that reflect circular values. The current institutional frameworks, dominant technologies and behavioral norms were created with a mindset that virgin materials have limited value and are abundant resources for the taking, making, and disposing of. As such, they reflect short-sightedness and have resulted in a lock-in of linear thinking – which is reflected in building industry practices.

New methods of collaboration are needed in the building industry that facilitate in high order learning. In order to maximize the potential of CE and harness the material value of our existing building stock for re-use, there is a need for new ways of collaborating in which face-to-face dialogue, goals and visions, process work and knowledge generation are central features.

Collaboration tools which work to facilitate meaningful face-to-face interaction and dialogue between actors, help facilitate the co-creation of goals and visions, assist in planning circular processes, and aid in the generation and documentation of new knowledge are needed. Such aspects will be extrapolated upon in the following subsections.

7.2.1 Dialogue

The building industry is defined by a highly cross-disciplinary, inter-organization approach to problem solving. To manage the complexity, project structures tend to be quite conservative and locked-in (Brown & Vergragt, 2008; Bonanomi, 2020; de Jesus et al., 2017). When approaching new types of problems, such as how to circulate materials for re-use, project structures and individual actor roles need to be renegotiated through pioneering boundary work (Bos-de Vos et al., 2019). One of the keys to creating a successful collaboration is time spent, early in the building process, solving problems through discussion – in a best-case scenario, face to face. The circular building process is dependent on the early contribution of stakeholders ((Bonanomi, 2020) and integration of their specific embedded knowledge (Carlile, 2002).and material expertise. In order to shape positive network dynamics (Leising et al., 2018) the relational aspects of collaboration must be taken into account. CE building projects will succeed when collaborations logics transition from "firm-centric" towards "network-centric" (Pieroni et al, 2019).

7.2.2 Goals & Visions

Establishing shared values and aligned goals are key mechanisms by which committed relationships are built between actors (Leising et al., 2018). Actors should actively participate in decision making and idea generation. Through such contributions, actors are given more agency over the project, which is key to inter-organizational knowledge sharing (Cheng et al., 2008). Furthermore, collective visualization and scenario building are keys to higher order learning (Brown & Vergragt, 2008) in which actors participate in "joint action" towards a desirable future (Leising et al., 2018). In the case of this thesis study, the desirable future is conceived of as circular building industry that prioritizes cyclical material flows.

7.2.3 Process work

In the novel circular building projects, actor roles become less demarcated and more fluid, meaning actors not only need to work across knowledge boundaries, but they also need to "cope with the changing boundaries that define their work" (Bos-de Vos et al., 2019). Moving through such change processes is complex. Often times actors sitting the middle of such processes are need of "social integration mechanisms to facilitate information exchange" (Gluch, 2020, p.373) or rather boundary objects (Star, 2010) which work to create behaviors aligned with circular goals and values. Tools, which facilitate discussion, unify goals and visions, and visible circular processes are needed to orient collaborations that results in sustained interaction of collaborators and yield higher order learning.

7.2.4 Knowledge generation

Collaboration is formed with the goal of creating some type of value (knowledge created, knowledge contributed, or knowledge acquired) for the partners involved. Collaborations that combine the aforementioned types of value result in "jointly held knowledge" (Cheng et al., 2008), which leads to trust and reduces the uncertainties associated with exploring new territory. Collaborative partners that exhibit both absorptive capacity and resource fitness are more likely to contribute to the diffusion of knowledge. In order for innovation projects to lead to higher order learning, in which collaborators experience a change in interpretive frames and problem-solving objectives, the collaboration process may be reflexive (Brown & Vergragt, 2008; Cheng et al, 2008; Leising et al., 2018). Therefore, a collaboration tool should focus on amplifying and communicating key learnings between partners, across project phases. Furthermore, emphasis should be placed on communicating and preserving key learnings beyond the project boundaries for a) maximum value capture and b) for helping shape desirable conditions for such innovations to exist outside of the protected space (Brown & Vergragt, 2008; Schot & Geels, 2008).

7.3 Moving forward

The Assumption Game was created to facilitate dialogue with actors about essential elements of collaboration (in general, such as a social phenomenon) but also to glean insights into how they experience collaboration in the context of CE building projects. It was an opportunity to bring up topics of responsibility and competition where new delineation of actor roles and open sourcing of key findings were presented as essential elements of CE projects. There was consensus by actors that such things matter, which is evidence of a change in values and recognition that the dominant management frameworks such as the "iron triangle" are not suitable for CE innovation projects. Furthermore, it was an opportunity to revisit findings from the literature and find out if they resonated with the actors. As an example of such things all actors felt strongly that CE goals must be set from the beginning of a project and there is definitely a need for better coordination of circular value chains. All of the discussions brought forth by the assumption cards helped solidify and validate the ideas for a Collaboration Tool. The Assumption Game was an integral, and strategic part of creating a specification for the Collaboration Tool which will be presented in the following chapter.

8

THE DESIGN SPACE

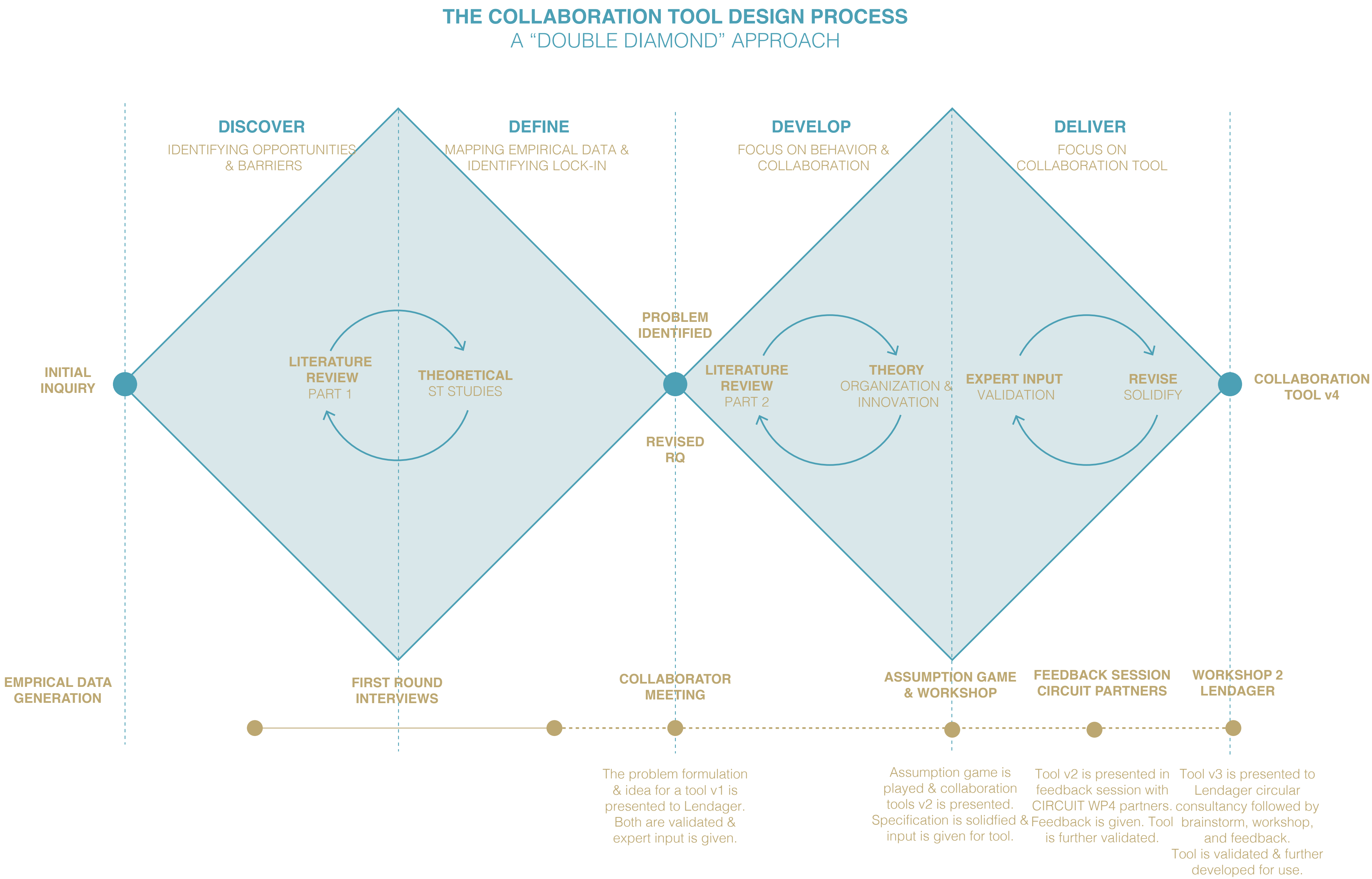

THE COLLABORATION TOOL DESIGN PROCESS
A "DOUBLE DIAMOND" APPROACH
DISCOVER
IDENTIFYING OPPORTUNITIES & BARRIERS
DEFINE
MAPPING EMPIRICAL DATA & IDENTIFYING LOCK-IN
DEVELOP
FOCUS ON BEHAVIOR & COLLABORATION
DELIVER
FOCUS ON COLLABORATION TOOL
INITIAL INQUIRY
LITERATURE REVIEW PART 1
THEORETICAL ST STUDIES
PROBLEM IDENTIFIED
REVISED RQ
LITERATURE REVIEW PART 2
THEORY ORGANIZATION & INNOVATION
EXPERT INPUT VALIDATION
REVISE SOLIDIFY
COLLABORATION TOOL v4
EMPRICAL DATA GENERATION
FIRST ROUND INTERVIEWS
COLLABORATOR MEETING
ASSUMPTION GAME & WORKSHOP
FEEDBACK SESSION CIRCUIT PARTNERS
WORKSHOP 2 LENDAGER
The problem formulation & idea for a tool v1 is presented to Lendager. Both are validated & expert input is given.
Assumption game is played & collaboration tools v2 is presented. Specification is solidfied & input is given for tool.
Tool v2 is presented in feedback session with CIRCUIT WP4 partners. Feedback is given. Tool is further validated.
Tool v3 is presented to Lendager circular consultancy followed by brainstorm, workshop, and feedback. Tool is validated & further developed for use.

Figure 26

8 The Design Space

It is the aim of this chapter to present the iterative process which has led to the design of a Collaboration Tool, as illustrated in **Figure 26**. Although presented as the final step of this thesis study, the design process was conducted in parallel to the literature review, theoretical study and generation of empirical data presented in previous chapters and is the accumulative result of these findings. The Collaboration Tool has been through four iterations, each of which have been subject to input from actors included in this study. The tool will be presented primarily in images in the following sub-sections following the double diamond approach illustrated in **Figure 26**.

8.1 Discover

The idea to create some kind of an "organization" or process tool was brought into the project from a previous study (Hill-Hansen, 2021) and was supported findings in the literature review on CE and the building industry. Through study of existing project frameworks (contracts, tenders, and sustainable certifications) it became apparent that these frameworks were developed with linear thinking, provide very little to support circular building processes (**Figure 16**). As such, there is a need for organization tools to facilitate circular building projects, which are highly collaborative in nature.

It is emphasized in the literature review and theoretical frameworks that vision creating, communication, common language, and so on are all critical elements to successful innovation projects. The idea was born to create a tool for collaboration, that would work as a boundary object (Star, 2010) to help facilitate new collaborative behaviors for CE transformation projects.

boundary objects that bridge pragmatic knowledge boundaries, where the conditions of difference, dependence and novelty are present in CE building projects and the need for transforming localized, embedded, and invested knowledge is fundamental to establishing new behaviors for circular processes.

Collaborations for CE are cross-disciplinary and inter-organizational, meaning the actors have a diversity of experience, which is both embedded, invested in their communities of practice and localized around the unique set of problems (the building project).

CE innovations rely on the expertise of building industry actors, who's understanding of technical process and material properties must be transformed from linear to circular practices.

A collaboration tool, which serve as pragmatic boundary objects, in which knowledge is mediated and transformed between collaborators throughout the innovation process can aid the knowledge broker (PM, consultant, resource coordinator) to organize, document, and communicate new knowledge. Given the right design, such a collaboration tool can also inspire co-creation processes in which all actors contribute to vision creation, goal setting, and problem solving.

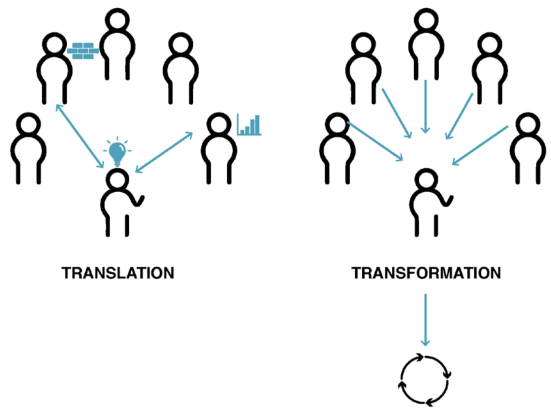


Figure 27

8.2 Define

Most of CIRCUIT actors included in this study have a project management role in the material innovation setting. They expressed a struggle to organize project actors around new circular processes. Many of which projects are happening in the context of transformation projects, in which material re-use is central.

The collaboration tool is designed to aid project manager, circular consultants or resource coordinators who sit in the middle of a project with the role of both translating and transforming the *embedded*, *invested* and *localized* knowledge of project collaborators around the circular innovation project. (**Figure 27**)

The first version of the Collaboration Tool was presented to Lenadger Group in a meeting (**Figure 28**). At this point the idea of the tool was validated as a recognized need for circular consultancy. It was agreed that one of the main goals for the tool was to communicate knowledge between collaborating partners.

It was also determined that the tool should embody the following characteristics:

- *Adaptable* to different innovation scales, from circulation of a single material for re-use to the renovation of an transformation of an entire building.
- *Agile,* in that it reflects the ever- changing nature of experimental innovation projects.
- *Transparent*: it makes clear what is known and what must be discovered throughout the project
- *Connects*: it works to connect collaborators across different phases of the innovation project, making visible individual contributions to the over-all project goals.
- *Communicates:* serves to create a common language between collaborating partners.

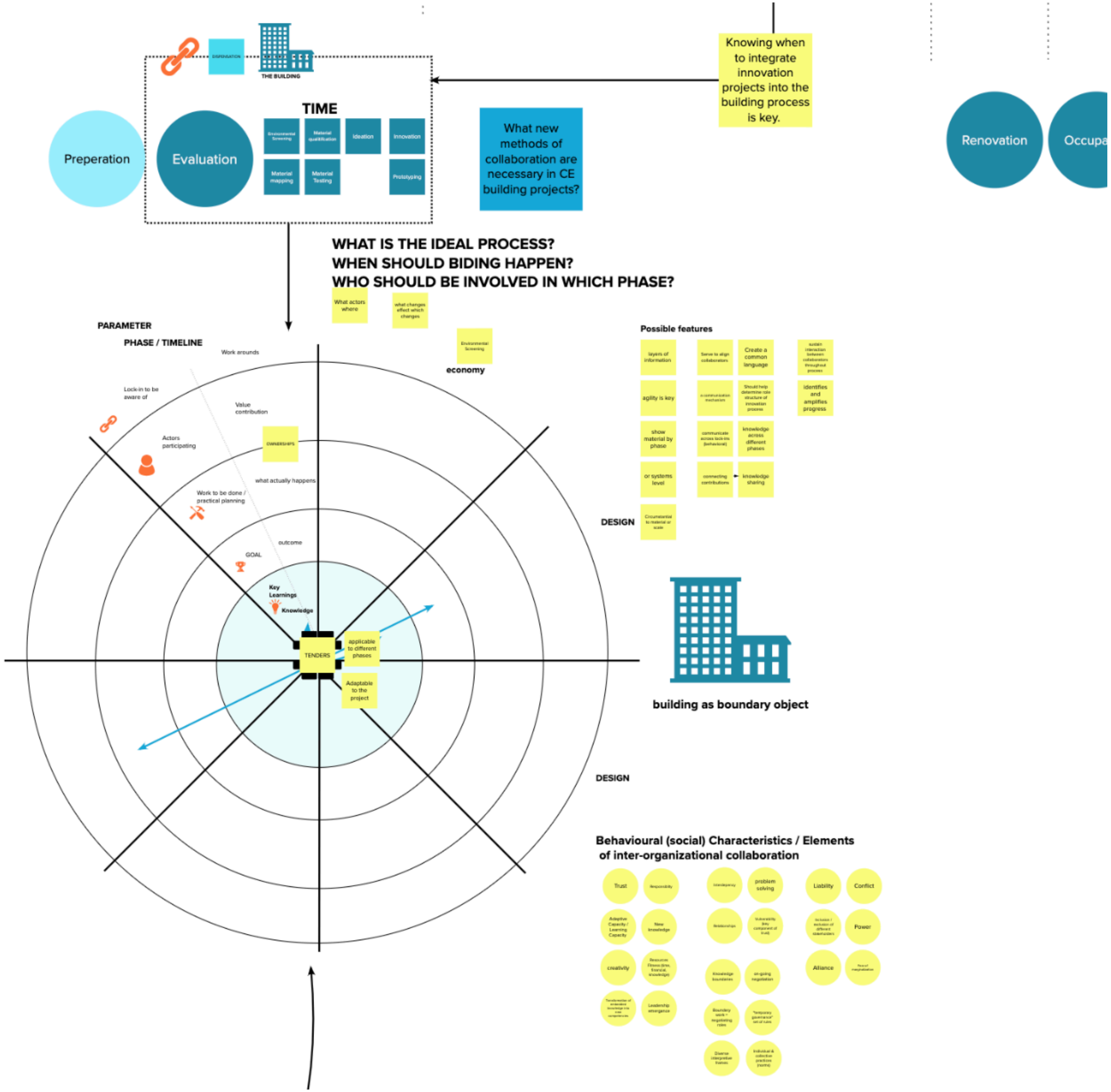
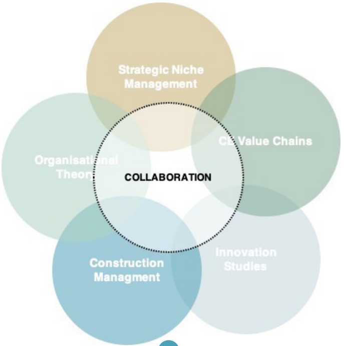


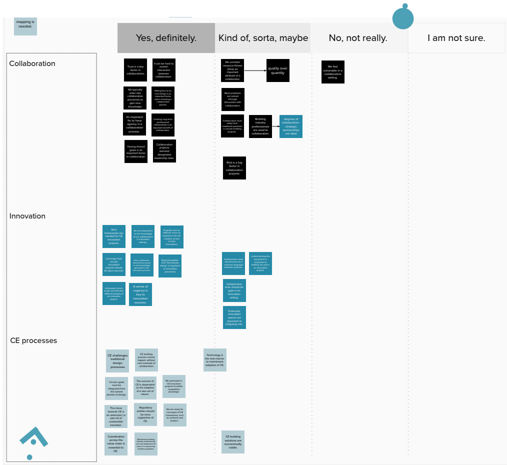
Figure 28

8.3 Develop

The process by which the tool has been generated has been iterative and inputs from the different fields of literature were studied were catalogued or rather accumulated and used as inputs for the design space.

1



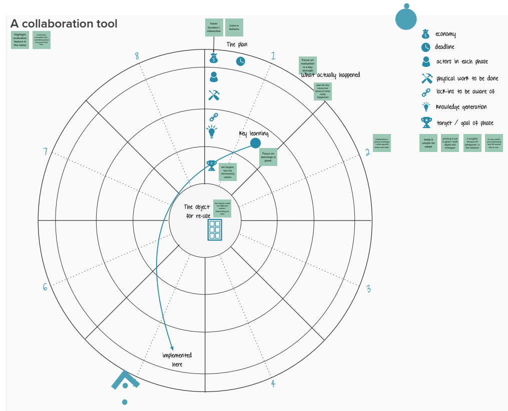


2

The Assumption Game was used to discuss key aspects of collaboration presented in the literature, check key findings discovered from first round interviews for consensus and glean insights from actors on how these aspects played out in a practical setting.

The results from the Assumption Game were recorded for comparison and inputs were added to the specification for the Collaboration Tool.

3



4

Following the Assumption Game a second iteration of the Collaboration Tool was presented. Feedback was given on the feasibility of the tool, it's usefulness, what types of criteria should be included and it what types of innovation process it could be applied.

Figure 28
The development process of the Collaboration Tool

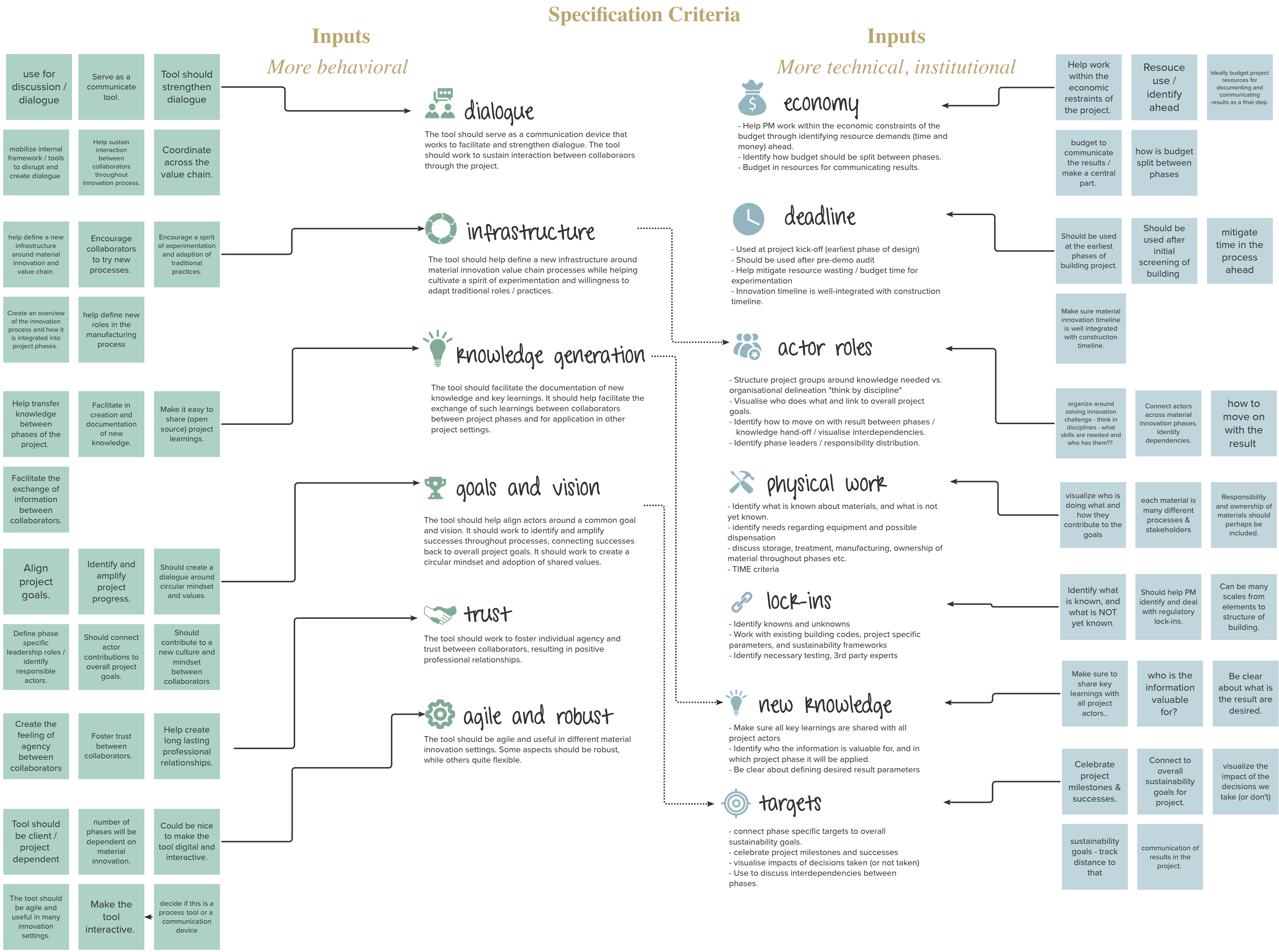


Figure 29

A specification for the collaboration tool. In green are criteria generated from the Assumption Game and in blue are criteria generated from feedback on the Collaboration Tool.

8.4 Deliver

The third iteration of the collaboration tool is presented in **Figure 30**. The Collaboration Tool was generated with the ambition to: Facilitate dialogue and communication between actors, help establish goals and visions for circular project ends, facilitate the boundary work essential to fostering new circular behaviors, and work to generate and document new knowledge generated throughout the innovation project.

1 The tool should be used in a project kick-off workshop. It can be used virtually on Mural, or printed and pinned on a wall. The tool is meant to facilitate discussion around the criteria described in **Figure 29**. For best outcomes a face-to-face meeting is desirable, perhaps at the building site.

2 The goal of project kick-off workshop is to document "the plan." Due to the nature of material innovation projects there are a lot of "unknowns" about the building. For this reason documenting "what actually happened" throughout the process is key to meaning learning outcomes.

3 At the end of each project phase, the PM should communicate new knowledge and key findings to all collaborators. This is an important ritual to emphasizing progress, and keeping actors invested in the innovation process. Likewise, major milestones should be celebrated in person.

4 Not all project findings will be relevant for application in another setting. Thus it's important that it is discussed what value generation is anticipated from the project start. That way the "key findings" fulfill the expectations of all project collaborators.

5 A key aspect of the tool is prioritizing time, energy, and resources for "reflexivity" in which documentation, and communication of project results is given it's own project phase.

On the following page in **Figure 31** are additional descriptions of how the tool might work.

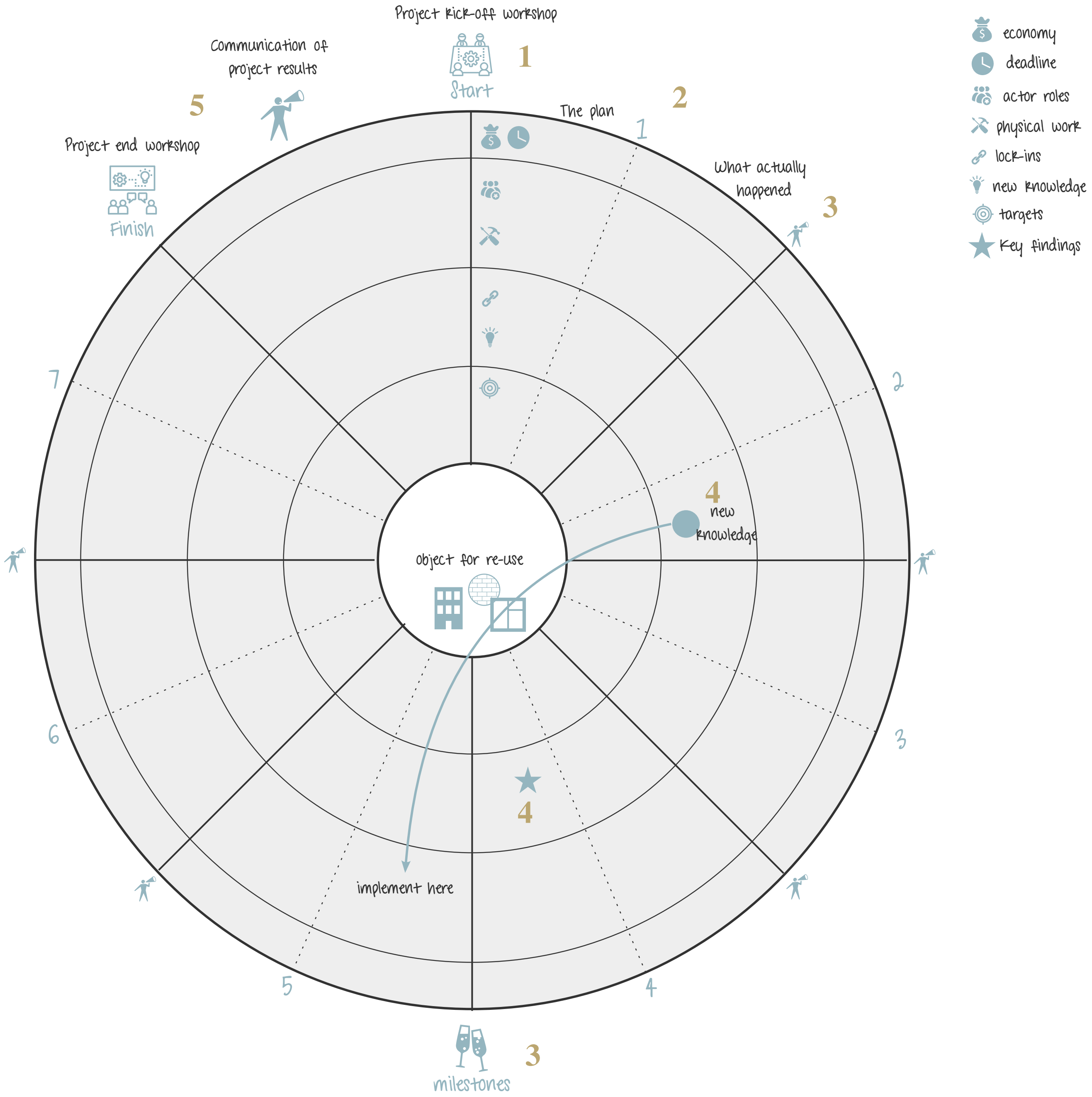
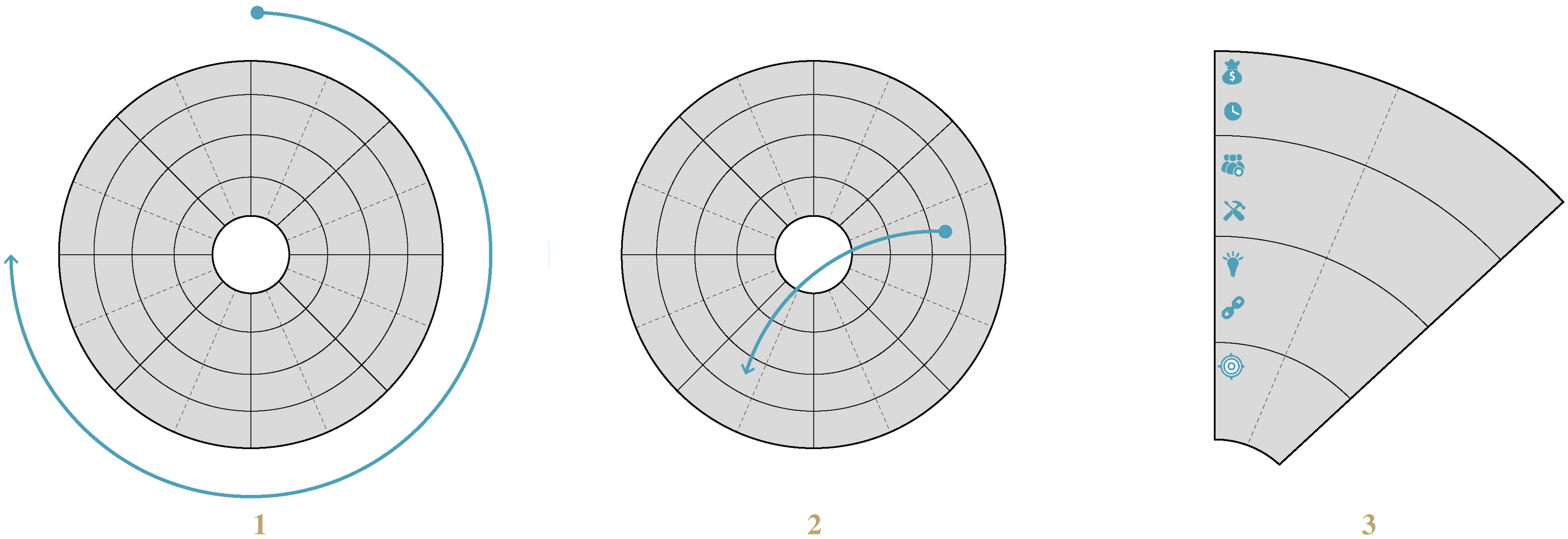


Figure 30



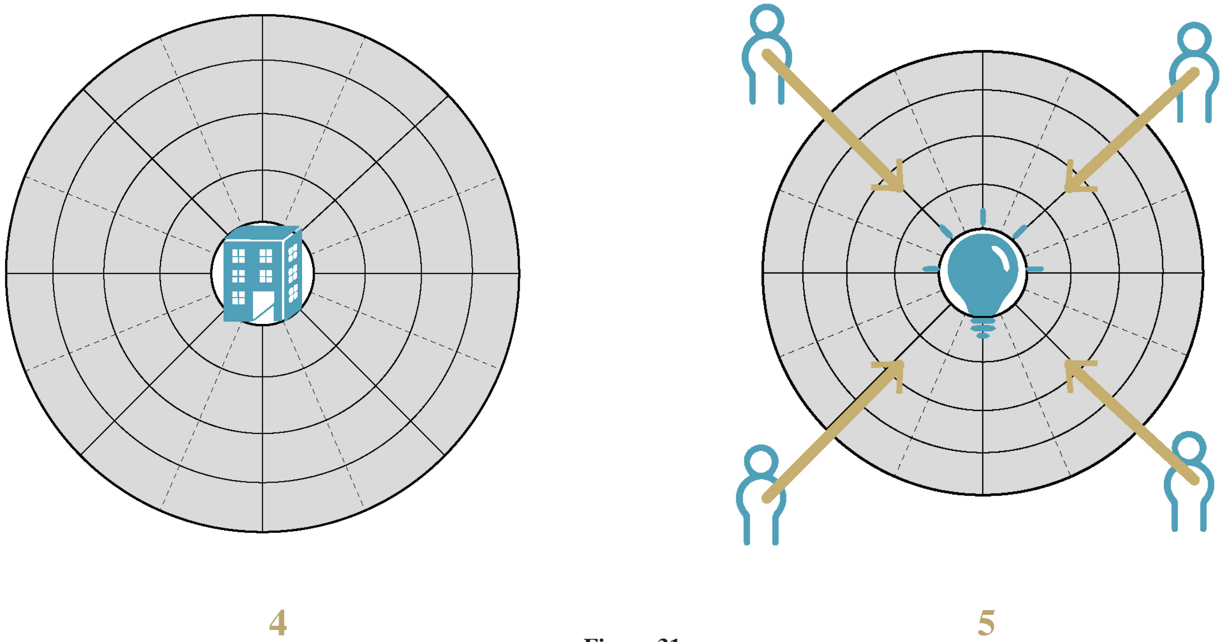


Figure 31

1 The circle is reflective of a chronological process. The scope of such a process and the number of phases should be determined in a kick-off workshop.
2 The circle is useful in communicating how the different phases are connected throughout the innovation process. It is possible to make visible where key learnings from one phase will be implemented in another.
3 The criterias presented are highly reflective of the building industry norms and are detailed in the specification Figure #. Such criterias should serve as a starting point for a new project, but are meant to be to flexible and adjustable to the problem solving context.
4 The tool should work to communicate across an object, or set of problems. That object could be an entire building, it could be a specific material, or it could be an aspect of the project like “fire safety.”
5 The tool should facilitate co-creation of solutions and work to inputs from all project collaborators, as early in as possible.

8.4 Deliver

While the Collaboration Tool has been developed to a use-able degree there is a lot of room for improvement. For example, the tool should be accompanied by some kind of "library" for key material findings. This could be an open-source website, it could be part of a data-base. In any case, as new knowledge is generated about the processes by which materials are being re-used should be documented and shared. Such findings will hopeful impact CE material certifications, building codes and mitigate some of the perceived and real risks associated with material re-use.

A big part of "improving" on the tool is taking it out of the "laboratory" and applying it in practice. Until then it's hard to evaluate the feasibility of such a tools usefulness in practice. As such, there is an intention to continue developing the tool with several of the organizations who participated in this study. The iterative, co-creative process by which the tool was developed ensures a likelihood of implementation. Once the tool has been implemented in practice, developing some kind of "how to use me" or staging guide will be important. One of the keys to participatory design processes is equipping the facilitator with the knowledge they need to stage a workshop.

This Collaboration Tool is only one answer to the "types of collaboration tools need to facilitate circular processes." The most important part of this exercise was generating the knowledge behind the tool. It's not often in a practical setting that the project manager has time to study theoretical concepts from organisation and innovations studies. It is the aim of this "design space" to equip such actors with the specification (**Figure 29**) which embodies many of the key concepts and concerns. Such learnings can be applied in other cross-disciplinary, inter-organizational collaboration settings. Such concepts are central to higher order learning and will suit a diversity of problem solving contexts.

Figure 32

"It looks like a really great tool because it focuses on the evaluation part, because that's often the part that's missing in all of our projects, that we can set goals, we can set strategies...But we often don't do evaluations and to accomplish to accomplish this tool to be successful. We also have to have resources to do the evaluation. Because it takes some time to make this assessment on what really happened and how it differs from the goal in the first place. But if we get that knowledge, that's really valuable knowledge to take into the next project."
(Municipal PM, Sustainable Construction & Reuse)

"My immense task right now is to mobilize this internal framework to make kind of a system that can deliver all these materials. In that sense, I kind of I need tools to kind of disrupt the dialogue with all these building sites. I need to understand how I can disrupt their traditional processes and say, hey, I need these materials. I need to be able to support a local project manager, who is my colleague and how he will take a dialogue with his subcontractors on the demolition and all this. So, I need a kind of process understanding, I need a kind of a cultural mindset with my colleagues, I need to kind of have supportive tools. Yes. To strengthen their dialogue, make it easier for them. Yeah. I need a new infrastructure of collaboration partners."
(Contractor, Head of Sustainability)

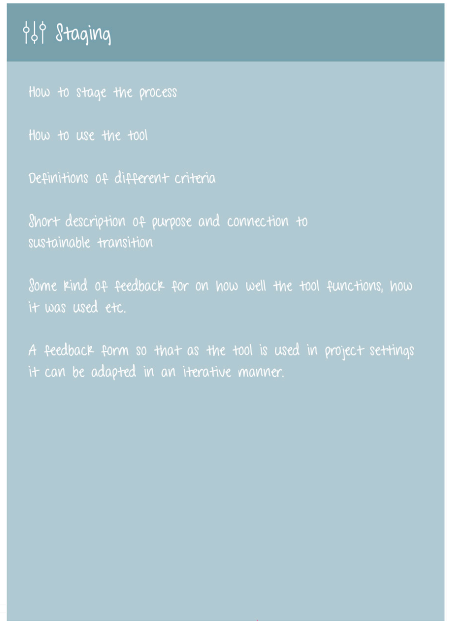


Figure 33

9
DISCUSSION

9 Discussion

9.1 Contextualizing this thesis

Rittel and Webber (1973) describe wicked problems as complex social and cultural phenomena. Sustainable transition literature offers a systemic perspective on long-term, societal change need to address the wicked problems associated with climate change. This thesis began with aim of applying this systemic approach to analyze what the current barriers and opportunities are to implementing CE in the danish building industry. From this initial systemic study, it was observed that while technical and institutional lock-in (Unruh, 2000, 2002) certainly limit the ways in which CE can be implemented in the Danish building industry, they are only part of the equation. In Unruh's original concept of lock-in the behavioral and social conditions were considered to mutually reinforce the technical and institutional lock-in. Such aspects, however, are often breezed over in the sustainable transition literature.

Through the lens of MLP (Geels, 2002; Geels & Schot, 2007; Seto et al., 2016) such behavioral and social conditions are conceived of as the "norm" or "accepted way of doing things" and are represented by regime practices. In SNM (Smith & Raven, 2012; Schot & Geels, 2008) the role of highly social acts such as learning, networking and visioning are all considered integral elements of creating transition pathways for sustainable transition. And while the literature on CE in the building industry identifies a need for the design of new value chains reflective of circular processes, it too has a tendency to follow the same approach of transition literature in which a majority of the studies focus on highly technical and analytical aspects of CE.

So, while the social and behavior elements are identified as keys to reconfiguring the building industry for sustainable transition, the literature doesn't provide much insight into how to change such conditions. In contrast to the dominant technocratic approach of the aforementioned literatures, the results of the empirical data generated in this study made visible the need for behavioral changes among building industry actors working on CE demonstration projects. Actors expressed a need to generate knowledge through cross-disciplinary approaches to problem solving in an inter-organization setting. Such actors identified dialogue, collective goal setting, relationships building and experimentation as the keys to unlocking circular opportunities. It was expressed that new methods of collaboration were needed to successfully execute circular demonstration projects.

Once collaboration, a highly social and behavioral phenomena, was identified as a central issue to circular innovation, the theoretical framework expanded to include insights from organizational theory, innovation studies and sustainable project management. Opening this door provided insights into concepts such as boundary work and role structures (Bos-de Vos et al., 2019); absorptive capacity and resource fitness, (Cheng et al., 2008; Gluch et al., 2020); value creation and high order learning (Leising et al., 2019; Brown & Vergragt, 2008) all of which are central to building productive collaborations. General learnings gleaned from these fields were translated to suit the needs of the Danish building industry's circular frontrunners.

The result of which is the in the design of a boundary object (Carlile, 2002; Star, 2010), the Collaboration Tool conceived with the goal of facilitating the creation and exchange of knowledge between building industry actors and to strengthen circular networks through collective dialogue and goal setting. Such a tool will best serve project managers and circular consultants who have a central role in steering circular innovation projects. Furthermore, the tool should assist in value capture so that the key learnings can have impact beyond the demonstration project and work to co-evolve the niche and regime.

This thesis aimed to provide insight into the behavioral and social conditions of sustainable transition, through the lens of niche, circular innovation projects. The findings from this thesis are perhaps most applicable to the emerging body of literature on Sustainable Project Management and are certainly indicative of the approach applied in novel field of Sustainable Design Engineering.

9.2 Limitations of this study

At the beginning of this thesis project all Danish CIRCUIT partner organizations were invited to participate in an interview, many of which were unresponsive. At the time, the purpose of the thesis wasn't totally defined which likely had an impact on the level of participation. The "big picture" of what is going on in the Danish building industry, created by the empirical data generated in this study would have been better defined if more perspectives and voices contributed. While many of the building industry professions were represented in this study it would have been nice to hear from influential actors such as investors and politicians.

The first round of interviews was semi-structured and quite open to the interest and objectives of the interviewee. This first interaction was really about opening up and "discovering" a problem. In contrast, the second set of interactions, the Assumption Game and workshops were quite structured and highly focused on "developing and delivering" the Collaboration Tool. It may have served the study to have a "defining" discussion with actors to better follow the "double diamond" approach Figure #.

Through discussion with the CIRCUIT actors many different demonstration projects were described, all of which are novel and focusing on different circular building principles. While the aim of this study was to paint a broad stroke, it could have been very meaningful to instead focus on a few cases. Flyvbjerg (2006) argues for the importance of practical knowledge generated through case- study research and argues that a discipline without exemplars is an ineffective one. Case-studies are said to deepen the understanding of an emerging concept from both a "Understanding oriented and an action-oriented perspective" (Flyvbjerg, 2006, p.229). Given the historically pragmatic nature of the building industry, conclusive and focused case-studies may have been a better approach to reach the target audience.

To that end, the feasibility of the Collaboration Tool is yet to be determined. This thesis would have been strengthened had the Collaboration Tool been actively tested within the scope of this study. It's very important that the tool is taken from the "laboratory" and used in practice. It will first be truly validated as useful, once tested in a real-life setting.

9.3. Opportunities for further research

A central aspect to the pedagogical approach of the Sustainable Design Engineering is the field of Participatory Design. Such an approach certainly informed the methods taken in this study, such as the design of the Assumption Game. It was however beyond the scope of this study to incorporate this body of literature in a central way. There is a great opportunity to apply such a theoretical framework and follow the Collaboration Tools' iterative development (beyond this thesis project) and conduct a study on the role of boundary objects in consultancy work.

CIRCUIT is an exemplary of a Bounded Socio-Technical Experiment (BTSE) (Brown & Vergragt, 2008) that is still in its beginning phase. In this study, CIRCUIT served primarily as the context or site for empirical data generated and at this point in time, it's too early to analyze the quality of such a large scale, sustainable transition experiment. There is however an opportunity in the future to study the structure and organization of CIRCUIT more in-depth and evaluate the role of such a BSTE a form of reflexive governance (Loorbach, 2010).

This study merely touched upon the complexity of behavior as a condition for socio-technical change. Given the complexity of the social and cultural problems resulting in and presented by climate change, there is a need for Design for Sustainability literature to explore in an in-depth way the impact of behavior in all sorts of design contexts. For example, many of the CE building principles presented by the building industry today, such as Design for Disassembly and the many Product Service Systems will only succeed in the pursuit of circulating materials through the development of new behaviors. Behavior is an essential element to the promise of CE, that cannot be overlooked.

10
CONCLUSION

What are the opportunities for and barriers towards implementing circular economy in the Danish building industry?

What new methods of collaboration are necessary in circular building projects?

What kind of tool is needed to facilitate such collaborative interactions?

10 Conclusion

This study began with an investigation of the barriers towards and opportunities for circular economy in the Danish building. The methods by which this investigation were conducted included literature review, theoretical exploration and discussion with building industry actors who are currently involved with circular building projects.

The literature on sustainable transition studies and CE in the building industry are of a highly technocratic nature, meaning their focus is on technical and institutional needs of sustainable transition and put very little emphasis on understanding the behavior conditions which mutually reinforce the technical and institutional. At the same time, these bodies of literature emphasize the need for new norms, cultural and social conditions in which new technical and institutional innovations can thrive.

Throughout this project it was discovered that there is concensus about the opportunities for and barriers towards implementing CE in the Danish building industry. Examples of such opportunities include political will and a slow up-take of institutional conditions that are more hospitable to CE. Though harder to define, a change in discourse and attitude towards CE are evidence of a change in mindset and values. It is recognized that circular approaches to building design are needed and that the linear thinking of the past is insufficient to meet climate targets.

Many actors see an opportunity to maximize the value of the existing building stock and are in favour of the "Renovation Wave". As such, emphasis is currently being on transformation projects in which structure, building elements and materials are being circulated for re-use. The general discourse around why we must preserve material worth is changing, which is key to implementation of all the circular building principles. Without such a change in perception, the likelihood of reaching a sustainable transition of the building industry is low.

Technical and institutional barriers towards implementation of CE are actively being investigated in on-going demonstration projects. Such investigations work to address the following barriers: a misalignment between market-mechanisms and the long-term value proposition of CE building principles; the fluctuating market for recycled materials make project economy hard to predict and lack of access to materials risks slowing down building processes; and there is a need for better building material information data so that the issues of access, material certification, safety and availability can be addressed.

The results of such on-going circular demonstration projects are highly dependent on the quality of interaction between collaborative partners. Meaning, that while little emphasis has been placed on the behavioral and social conditions that define circular innovation projects, the outcomes are highly dependent on the creation of conditions conducive successful collaboration. As such, new methods of collaboration are needed that work to create new behaviors around the circular problem solving contexts.

The building industry is highly characterized by its cross-disciplinary, inter-organizational approach to problem solving. Meaning, collaboration is not a new practice for the industry, but the processes by which actors must interact in CE building projects demand the demarcation of new roles and collaborations must be formed under the premise of new success criteria.

The success of CE innovation projects is dependent on the integration of the embedded, invested and localized (Carlile, 2002) knowledge of building industry professionals. Meaning that knowledge must be communicated between new constellations of actors and contributed at different times in the building process, to be translated into new circular practices. Such a transformation of knowledge is dependent on the adaptive capacity and resource fitness (Cheng et al., 2008) of project collaborators.

It is of great importance that the key learnings from CE building projects are transferred beyond the project. This can happen through proper documentation and sharing of such findings but will be most impactful when project collaborators apply the new principles in another setting. According to sustainable transition literature, the co-evolution of the niche and regime tends to happen when new practices are replicated outside of the niche, innovation space. Carlile (2002) states that "when knowledge is proven to be successful, individuals are inclined to use that knowledge to solve problems in the future" (Carlile, 2002, p.446).

In order for actors to replicate new practices, they first have to proven to be successful. Therefore, it's essential that collaboration for circular innovation create conditions that are hospitable to higher order learning, in which new mindset, values, and interpretive frames (Brown & Vergragt, 2008) are adopted by actors. The complexities of navigating such social and behavioral conditions require actors well equip for the job.

CE innovation projects typically have a project manager or circular consultant who has a central role in determining project outcomes. Such actors are tasked with role of facilitating a complex exchange of information between collaborators while also work around linear building industry lock-ins (institutional dimensions). In order to do so, they must plan and execute circular processes, and steer the project in the direction of sustainable, circular outcomes. Such actors are in need for new ways to communicate new knowledge generated (of the technical nature) between collaborators and facilitate the creation of new behaviors for circular collaboration.

Tools, models, diagrams or objects which facilitate the visualization and documentation of such knowledge are needed to organize project structure and create common ground between collaborating partners. Such tools are defined as boundary objects (Star, 2010) which work to communicate knowledge that is localized, embedded, and invested in practice across syntactic, semantic, and pragmatic knowledge boundaries (Carlile, 2002).

In this project the Collaboration Tool is presented as a *boundary object* which works to foster higher order learning in circular innovation settings. The Collaboration Tool works to facilitate dialogue and communication between actors, help establish goals and visions for circular project ends, facilitate the boundary work (Bos-de Vos et. al, 2019) essential to fostering new behaviors, and to generate and document new knowledge generated throughout the an interative, reflexive innovation process, all of which conditions are essential to higher order learning.

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APPENDIX

Appendix Documents

Author Declaration Form:
Required by the university after a group split.

Mural Boards:
Each page has a pdf copy of a mural board on it. There is also a link to the mural boards digital location, where the reader can the board as a guest. At the date of this publication (May 28, 2021) this links were active, but may expire with time.

Author Declaration Form

Author Declaration

Author's declaration in connection with the split-up of group **Dani Hill-Hansen and Daniele Costantini in study program Sustainable Design; MSc Engineering, semester 4, Copenhagen, 2021**

As per March 7, 2021 a split-up of the project group is carried out. The group is divided, so that the following students (**Dani Hill-Hansen** and **Daniele Costantini**) work alone from now on.

We give consent to all parties to use the mentioned material after splitting up the group. The material developed together is as mentioned: All information collected in the **First-Round Interviews** (See attached table) and notes, discussion, transcripts derived from these interviews. Additionally, both students have access to all material generated and stored on our shared Google Drive folder "**Shared Speciale WEEK 10**" which contains articles, resources, notes, and other useful documents.

The split-up is approved and signed by all parties, after which the split-up is final. The author's declaration is inserted in the beginning of the respective project reports.

Copenhagen, 10 April 2021

Name and signature 1
Dani Hill-Hansen

Name and signature 2
Daniele Costantini

FIRST ROUND INTERVIEWS			
Date	**Format**	**Participants**	**Theme**
10/02	Informal interview / discussion	Thomas Sinding J.Jensen	Project introductions
16/02	Informal interview / discussion	Anders Sørensen Enemærk og Pedersen	Project introductions
19/02	Informal interview / discussion	Frederik Fenger Petersen København's Kommune	Project introduction
25/02 & 26/02	Informal interview / discussion	Jens Rungee DGNB Chef Consultant København's Kommune	Project introduction
25/02	Informal interview / discussion Meeting with collaborator	Tim Tolman CØ consultant Lendager Group	Directions to take in project
01/03	Informal interview / discussion	Øystein Leondardsen, Project Manager in Områdefornyelsen (Urban Renewal) København's Kommune	Project introduction
04/03	Informal interview / discussion	Per Richard Hansen Professor AAU	Research Question and Thesis approach. Theories and empirical data
08/03	Informal interview / discussion	Rune Andersen, DTU	Introduction
12/03	Informal interview / discussion	Jan Boström, SundaHus	Introduction
17/03	Informal interview / discussion	Simon, Realdania	Introduction
17/03	Informal interview / discussion	Thomas Mondrup, GBC-DK	Introduction
18/03	Informal interview / discussion	Luzie Ruck, Frivilligt Bæredytighedsklasse	Introduction

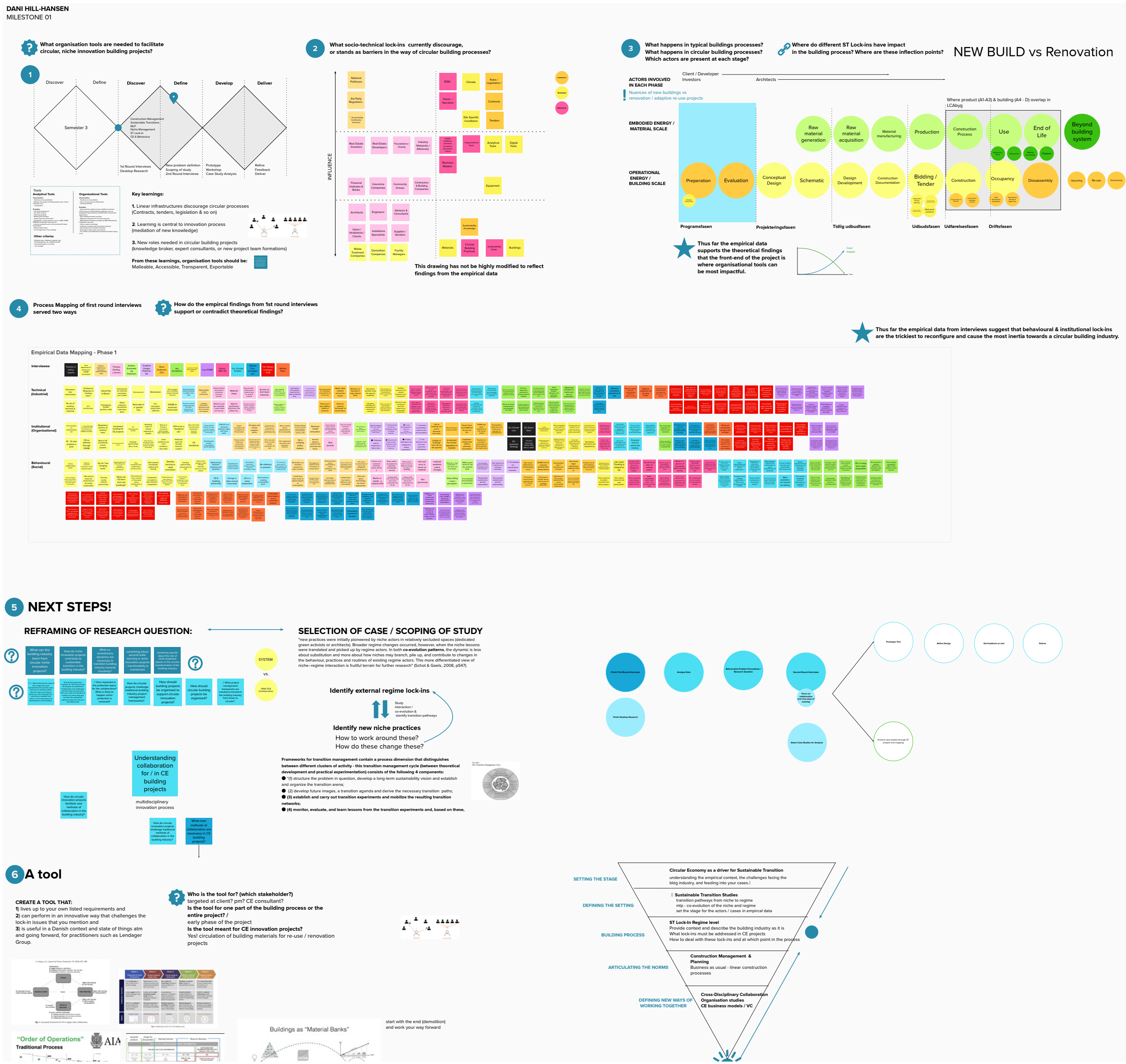
2/3

SHARED GOOGLE DRIVE FOLDER
SHARED Speciale WEEK 10

3/3

Mural Boards

Milestone 1 Presentation



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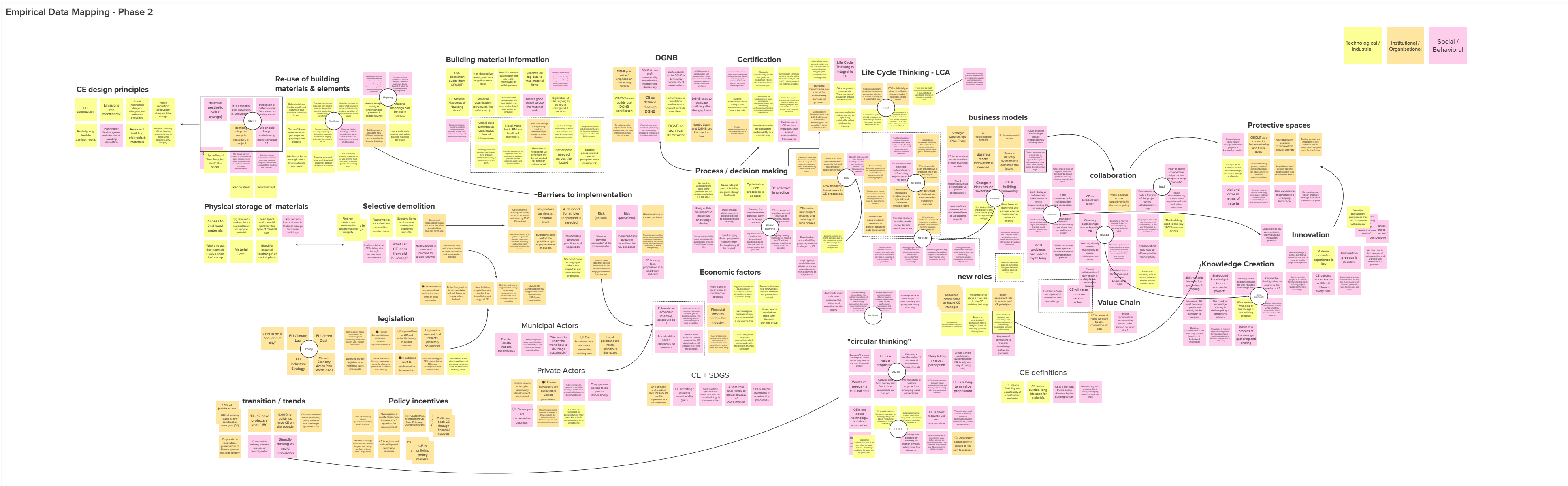
Mural Boards

Empirical Data Mapping



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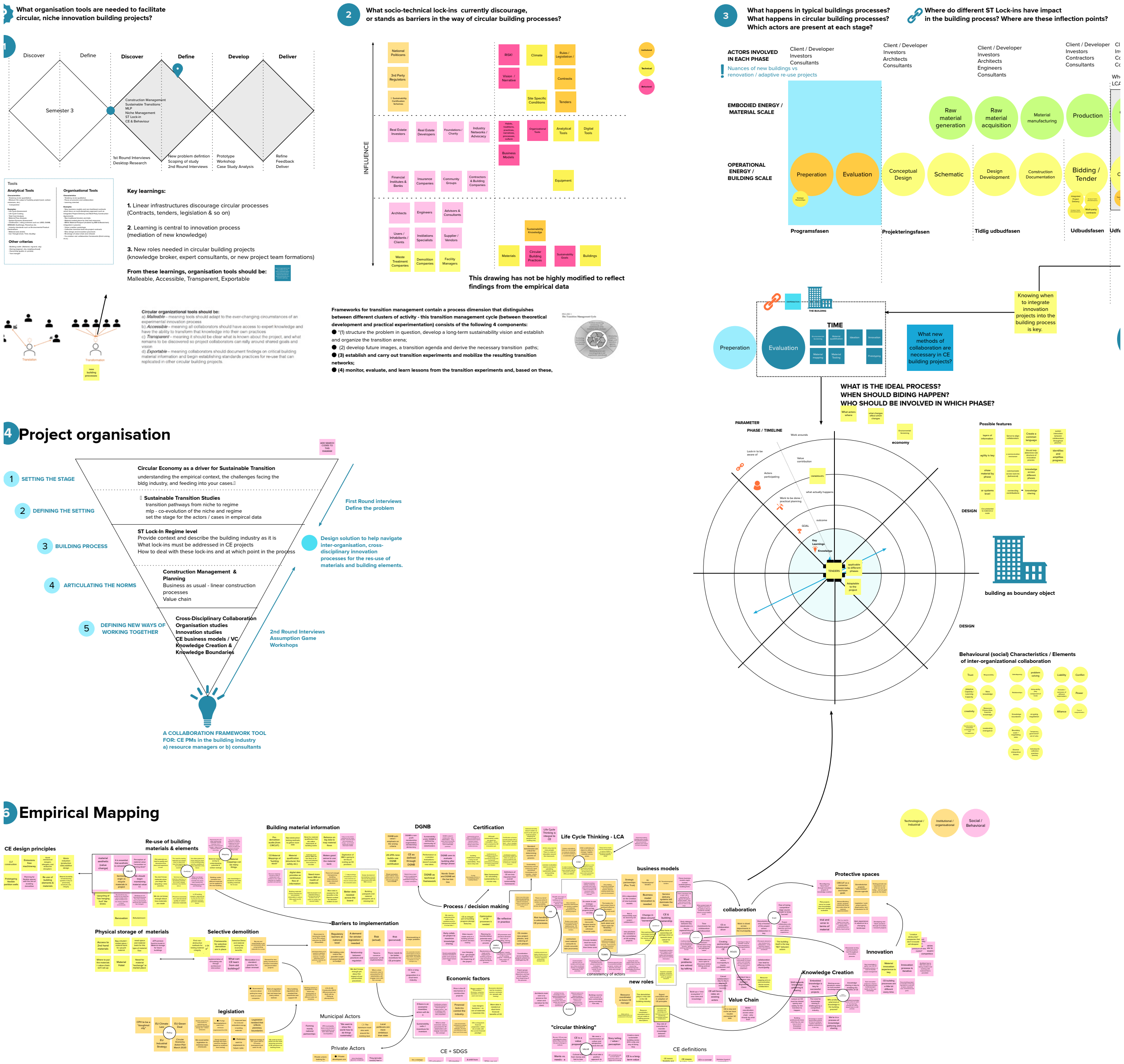
Mural Boards

Collaborator Meeting



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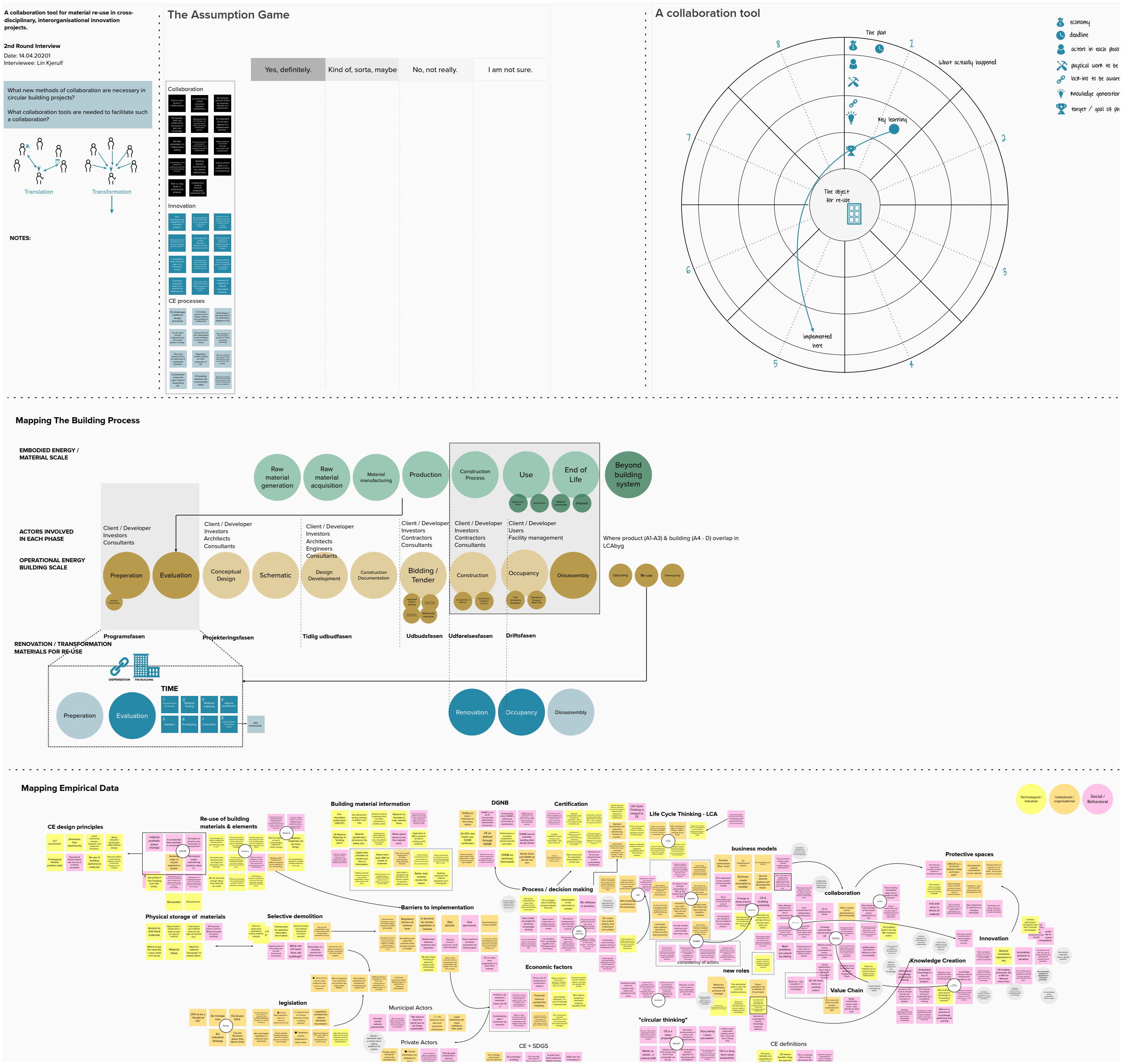
Mural Boards

2nd Round Interview



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A collaboration tool for circular innovation settings

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