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POSSIBILITIES TO PROMOTE CIRCULAR ECONOMY IN MID-RISE TIMBER CONSTRUCTION IN THE PROJECT PLANNING AND EARLY DESIGN PHASES

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ABSTRACT: This paper examines the client's decisions and actions taking place in the early project planning phase that could promote a circular economy in mid-rise timber construction projects. During the early planning phase, the client has an integral role in setting targets for circularity that the assembled construction actor-network carries out and tries to accomplish. However, the current research lacks concrete conceptualization and categorization of how circular economy principles can be carried out by the client in mid-rise timber projects. Therefore, the paper analyses one mid-rise timber construction project that has promoted circularity in all the life cycle stages. The study is conducted using a qualitative single case study method to identify which actors, resources, and activities can be utilized in the construction actor-network to achieve circularity targets set in project brief. The main finding is that a single actor in the construction actor-network has limited resources to promote circular economy in a mid-rise timber construction project and collective activities among project members are required to achieve circular economy targets. To conclude, the paper adds to the existing research by clarifying the client's role in utilizing the full circular economy potential of the construction actor-network.

KEYWORDS: circular construction, timber buildings, actor-network analysis

1 INTRODUCTION

Globally, the buildings and construction sector uses 36% of the energy, produces 39% of emissions [1], up to 40% of waste [2] and uses 50% of all the extracted materials [1]. Raw material extraction and processing cause 90% of biodiversity loss [3] and it is estimated that only 9% of the extracted resources are circular, meaning that is the amount re-used annually [4]. These numbers highlight the connection between the buildings and construction sector and three current predicaments: climate emergency, resource scarcity and the biodiversity crisis.

Using engineered timber for construction has great potential in climate change mitigation. If 90% of the new urban population would be housed in mid-rise timber buildings, 106 Gt of carbon dioxide emissions could be saved by 2100 [5]. Besides increasing the use of timber in construction, a transition from the now dominant linear economic model towards a circular economy could significantly lower the negative environmental impacts of construction.

A circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems [6]. In a circular economy, materials and products are not taken out of the loop, but they are kept in the economy for as long, as efficiently and at the highest utility as possible. The emissions and use of virgin and non-renewable resources are minimized and the recycling of materials and products is maximized.

This paper presents design strategies that have been identified in the literature [7–11] to promote circularity in the built environment. Thereafter, circularity targets are presented that can be set to assure or promote the realisation of the strategies.

The paper focuses on the project planning and early design phases and the client's possibilities to promote circularity in the construction actor-network. Three key aspects support the chosen focus. First, research shows that most of the decisions that affect the circularity in construction projects are done in the early design phase [12]. Second, it is advocated in the project management and infrastructure project literature that the project planning phase is where the involved stakeholders have the best possibility to affect the final project and its outcomes [13]. Third, the clients are in a key position,

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since they can include circularity as a goal in a construction project at an early stage [14].
The role of the client and the requirements and objectives they set for a project are obscure in the transition from linear to circular construction. Therefore, by identifying applicable circularity targets in realized construction projects and key activities in achieving them, a client can make early-phase decisions promoting circular economy during the building's entire life cycle.
This article identifies and describes how the client can utilize assembled construction actor-network to promote a circular economy in mid-rise timber projects. The following research questions were formed for the article: which circularity targets are present in the selected case study's project brief and how have they been met in the final construction (1), which are the key actors in the early design phase to promoting circularity in mid-rise timber projects (2), and what resources are required from the gathered actor-network to carry out the needed activities to reach the set circularity targets (3).
The article is divided into five chapters: introduction, literature survey, research methodology, results and discussion and conclusion. The literature review presents a summary of the identified circular economy strategies and related targets and gives an overview of the actor-network literature. The research method describes the selected case study and how it was analysed. The result chapter consists of three sub-chapters that will present the findings for the set research questions. The aim of the single case study analysis is to understand how the construction actor-network was able to realize the circularity targets in the early design phase of the project. Finally, the article presents a discussion of the findings.

2 LITERATURE SURVEY

2.1 CIRCULARITY STRATEGIES

This chapter discusses and describes design strategies that have been identified to promote circularity in the built environment. These strategies are then combined into a conceptual framework for this research.
The definitions of circular economy vary but optimising resource consumption, waste generation and/or embodied environmental impacts and regenerating natural systems target the main principles of a circular economy [15]. In the buildings and construction sector, circular strategies are of such nature that they promote one or more of the key aspects of a circular economy. 16 circularity strategies were identified through the literature survey (Table 1). Strategies focus on design aspects that can be implemented in the early design phase of the project.

Table 1: *Circularity strategies and their short descriptions. Sources:* [7–11]

Strategy	Description
Design for assembly/ disassembly	Reversible connections that allow easy reuse of components.
Design with circular materials	Choosing or substituting conventional materials with materials that are local, renewable and/or have low negative environmental impacts.
Design for adaptability/ flexibility	Designing buildings that can adapt to future changes regarding use, function, and available materials.
Design with modularity	Lean production and standard solutions that allow easier replacement, flexibility, and recycling.
Design for prefabrication	Off-site construction that allows material and time optimisation.
Design with secondary materials	Using recycled or reused materials instead of virgin materials.
Design for durability	Designing long-lasting buildings with long-lasting components.
Design with standardised solutions	Using standardised solutions (dimensions of components or connections) to ease efficient replacements and recycling.
Design for component and material optimisation	Reducing the amount and variations of materials and components used.
Design optimised shapes/ dimensions	Design with precision and specification to optimise the use of material and space.
Design for accessibility	Providing easy access to connections of components to ease maintenance, repairs, and recycling.
Design for layer independence	Making components and materials independent from each other's lifespan.
Design for short use	Designing buildings for their specific performance span.
Design symbiosis	Using resource outputs from one building as feedstock to other buildings.
Design energy-efficiency	Designing buildings that operate energy-efficiently.
Design for sharing	Buildings where spaces or equipment are in common use and thus reducing the need for private ownership.

2.2 ANALYSING ACTOR-NETWORKS

One way to approach network-based research analysis is to identify and examine the combination of activities, resources and actors that have been organized to work toward a specific goal. This is a focal approach applied in IMP research[16] and is identified as the ARA model focusing on industrial networks where actors undertake

activities using various resources [17]. Actors are individuals, companies or firms [18], resources can be defined as a different mix of competencies and set of assets that are used in conjunction [19] and activities as actions carried out by the actors to reach a specific target [20].

Networks are a general and abstract concept that can be used all the way from describing and modelling a complex business market to understanding a specific relationship between companies [21]. This paper focuses on understanding how a specific group of actors have been promoting circularity in a mid-rise construction project. The article incorporates the ARA-model approach to network analysis to examine the transition from identifying circularity targets in the competition brief to designing how they can be achieved.

3 METHODOLOGY

There is a lack of understanding of how circularity targets can be implemented into mid-rise timber construction projects. Therefore, this paper incorporates a qualitative single-case study [22] to examine one mid-rise timber construction project that has implemented multiple circularity strategies. Therefore, this study examines qualitatively one mid-rise timber project that promotes circularity in many ways [22]. The case study approach was chosen since it provides rich descriptions of the phenomena in the real-world context and is suitable for exploring new research areas where little is known about the subject [23,24]. Additionally, the case study research strategy can be used to investigate and retain information on organisational processes [22,25] by incorporating questions of “how” and “why” to reach a complete understanding of the studied real-world phenomena [32].

The selected case project consists of a densely built cluster of social housing buildings. The 3–4 story buildings have a hybrid structure consisting mainly of timber, concrete, and steel. The buildings have post-and-beam frames of glulam timber, glulam timber slabs, steel connectors, and a concrete core. Additionally, cross-laminated timber (CLT) walls are used in the buildings for stiffening the structure and steel beams are used in places where extra strength is needed. Moreover, the project represents mid-rise timber construction that has been designed and constructed by accounting for the following circularity characteristics:

- low carbon footprint
- energy-efficiency
- the use of renewable low-carbon construction materials
- material-efficiency.

Furthermore, the selected case study has received praise for its architectural design in the media and in the scientific community. Architectural design can be identified as one of the key activities in the project's early design phase but requires other activities' support to reach different circularity targets.

The competition brief was identified as the main data source for understanding the circularity targets set by the client. To complement the case study analysis, photographs of the project during construction were studied and one semi-structured interview was carried out to collect data from one of the key actors in the early design phase. Interviews have an essential role in case studies to fully understand the studied phenomenon [22,26]. The project manager of the design phase was selected as the interviewee because people in this role generally have a good overview of the early design phase of the project. The design phase project manager also acted as the leading architect in the case project.

Interview questions focused on finding out which circularity targets were eventually reached and what activities, resources and capabilities were required from the early design phase actor-network. The interview was audiotaped, transcribed and analysed.

Case studies incorporate different analysis methods such as a thematic analysis where collected case data is categorized into themes through coding [25]. The selected and formed themes were based on the literature survey and two main categories were selected: circular economy and actor-network. The circular economy theme was divided into sub-categories: circular spatial solutions, circular construction materials and circular connections. Firstly, circular spatial solutions prolong the building's lifespan or lower the users' negative environmental impacts, for example, flexible and adaptable spaces, spatially efficient spaces, or spaces in common use. Secondly, the characteristics of circular construction materials can be defined as renewable, low-energy, low-emissions, carbon-storing, healthy, durable, local, resource-efficient, recycled and recyclable (a material does not have to be all the above to be considered circular). Finally, circular connections include joints and other means of assembly that are durable and allow flexibility, disassembly, replacements, and maintenance with little or no loss of the building's or its components' value.

Similarly, the actor-network theme was divided into sub-categories: actors promoting circular economy, activities promoting circular economy and resources required to promote circular economy. The aim is to link the identified actions promoting circular economy to a specific construction actor and understand what resources were required to realize the set circularity targets.

The results chapter is divided into three sub-chapters. The first sub-chapter presents circularity targets found in the competition brief and circular design strategies they promote. The second sub-chapter presents how these targets have been met in the project. The third sub-chapter identifies the key actors in the actor-network and their activities and resources that enabled achieving a circular project.

4 RESULTS

4.1 IDENTIFIED CIRCULARITY TARGETS IN THE COMPETITION BRIEF

This section presents how circular economy has been included in the competition brief. Table 2 summarizes identified targets and connects them to strategies presented in Table 1.

Holistic sustainability, which includes ecological, economic and socio-cultural sustainability is a key goal in

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the competition brief. The different aspects of sustainability are repeated throughout the brief, though it is not defined in greater detail how holistic sustainability should be achieved in the project. Even though the brief asked for holistic sustainability, this paper focuses on identifying how environmental sustainability was promoted.

The competition program states that the proposals are evaluated based on environmental quality, economic quality, sociocultural and functional quality, technical quality, process quality, and the quality of the area, including social and locational aspects. How these aspects have been considered must be shown in the requested drawing material and corresponding descriptions. The competition brief also states that interdisciplinary design efforts are highly appreciated.

The program asks for proposals that have a minimal burden on the global and local environments. They have specified that this includes resource-saving principles both during the construction and operation of the buildings and their external areas. Additionally, materials must be selected based on an LCA approach where the focus is on using building materials that can be produced locally or regionally with low energy consumption, and where materials from a renewable raw material resource are preferred. When choosing materials, consideration must also be given to robustness against expected wear and tear, which steers towards durability.

It is also stated that the project must consider efficiency in energy consumption, water consumption, waste management, materials, and land use. The buildings must reach at least a low-energy class in 2015. In addition, an environmental vision for the entire building is desired and its resilience to and handling of climate change is also included.

The competition brief also recommends pursuing a DK-DGNB silver or gold certificate. The competition organizers emphasized that the desire for a certain certification must not be perceived as something limiting further sustainability measures in the answer to the competition task. The DK-DGNB system is a Danish-adapted evaluation system that is based on the DGNB system developed in Germany. The DK-DGNB system is based on the three central pillars of sustainability: ecological, economic and socio-cultural sustainability, and these three are weighted equally in the evaluation process. Therefore, ranking in DK-DGNB can be seen as a tool to measure how well the competition proposal delivers holistic sustainability.

The competition program also included flexibility. The brief describes that apartments should provide space to live that is flexible and has the possibility of adaptation in case living situations change over time. The brief does not directly say that flexibility should be considered in the structural design, but the DNGB classification considers this aspect of flexibility and thus designing with it in mind helps achieve good scores in the ranking, which was required in the brief.

The competition brief also included targets supporting design for layer independence and accessibility. First, by specifying that all materials that have a shorter expected life span than the building must be able to be replaced easily, economically and with little inconvenience for the residents. Second, by stating that easy replacement of parts is highly appreciated.

Design for material and component optimisation is also vaguely promoted in the brief since it is stated that simple construction systems are preferred. Besides simplicity, the brief considers proven constructions preferable, which connects to standardised solutions and modularity.

One of the focuses of the brief is on social sustainability and some aspects of social sustainability promote circularity. Without directly demanding a sharing economy, the brief discusses its benefits and gives examples of it, such as sharing cars, shared guest rooms, and shared spaces to organize events. Moreover, the brief includes the option of constructing a separate community house, which can be used to facilitate sharing.

Table 2: *Targets from the competition brief and connected circular strategies*

Target	Strategy
Flexible apartments that can adapt to changing life situations	Design for adaptability/ flexibility, design for assembly/disassembly
Renewable materials	Design with circular materials
Local or regional materials	Design with circular materials
Materials with low embodied energy	Design with circular materials
Robustness against wear and tear	Design for durability
Low-energy class	Design energy-efficiency
DK-DNGB gold or silver certificate	Design with circular materials, design for assembly/ disassembly, design for durability, design energy-efficiency
Materials with short service-life must be easily replaced	Design for accessibility, design for layer independence
Simple solutions	Design for component and material optimisation
Common spaces	Design for sharing

The competition brief included sustainability targets in various ways. The project that won the competition and got built used a circular economy approach to respond to many of the things asked in the brief. It is to be noted that the brief never actually mentions circular economy. Nonetheless, the key aspects of the economic model were included and described with varying detail.

4.2 IDENTIFIED CIRCULAR ECONOMY RESPONSES IN THE CASE PROJECT

Table 3 explains how the project has responded to the targets set in the competition brief and how these responses have promoted circularity. The table also shows whether the targets were met, exceeded or undershot. In

Table 3: *Identified circular solutions in the case project and how they respond to targets set in the brief and how they promote different circular strategies*

Target	Response	Strategy
Flexible apartments that can adapt to changing life situations	Walls and openings can easily be altered, and apartments can be combined vertically and horizontally	Design for adaptability/ flexibility, design for assembly/disassembly, design for accessibility, design for layer independence
Renewable materials	Timber-based frame, CLT walls that are exposed on the interior, unplaned lye-treated timber boards in the interior, and exterior facades of untreated wood. Because of the vast use of natural materials the carbon footprint is estimated to be 50-70% of the conventional solution.	Design with circular materials
Local or regional materials	Using local or regional materials. The timber was mainly from Sweden and Germany.	Design with circular materials
Materials with low embodied energy	The structure is timber-based and has slow embodied energy	Design with circular materials
Robustness against wear and tear	CLT is used in walls and left exposed. Other interior surfaces of lye-treated timber. Maintenance is limited mainly to sanding and redoing the lye-treatment.	Design for durability
Low-energy class	Energy-efficient buildings with lots of daylight	Design energy-efficiency
DK-DNGB gold or silver certificate	DK-DNGB gold	Design with circular materials, design for assembly/ disassembly, design for durability, design energy-efficiency
Materials with short service-life must be easily replaced	Timber facades and interior panelling are designed to be easily replaced	Design for accessibility, design for layer independence
Simple solutions	Repetitive post-and-beam grid. Exposed CLT walls, untreated facades, lye-treated interior surfaces. Less material-layers than in conventional construction.	Design for component and material optimisation, design with circular materials, design for adaptability/ flexibility, design for assembly/ disassembly, design for accessibility, design for layer independence
Community house	Community house with common activities and community space with kitchen and toilets. Additionally, there is a maintenance-room for sharing of used objects, furniture, books etc	Design for sharing

some cases, when comparing the response to a target, the project delivered solutions that were better at promoting environmental sustainability than what was asked for. For example, the brief asked for flexible apartments that can adapt to changing life situations but the project consists on flexible buildings, in which changes can be made within apartment but also through combining apartments in various ways. However, it is to be noted that it was stated in the competition brief that proven structures are preferred and that the project is contradicting this as the proposed structural system is piloted in this project. However, the new system was deliberately chosen because the benefits to be achieved with it, such as flexibility, were well in line with the other targets in the brief.

4.3 ACTOR-NETWORK AS A CIRCULAR ECONOMY PROMOTER

The single case study revealed that three key actors can be identified from the early design phase that are responsible for promoting circular economy (Picture 1). All the actors were in tight collaboration throughout the design phase with varying roles and complementing resources.

Firstly, the client can be seen as an enabler for the project by first setting targets in the project brief and later collaborating with other network members to achieve and approve a quality product for the tenants. Even though the client's role is more passive than those of the architects and engineers, the choices made by the client have a great impact on the overall sustainability of the process. Specifically in this project, the client was open-minded and allowed the architect and the engineer to create innovative solutions as part of promoting circularity. The client was, understandably, sceptical about some of the suggested solutions, especially of those concerning the

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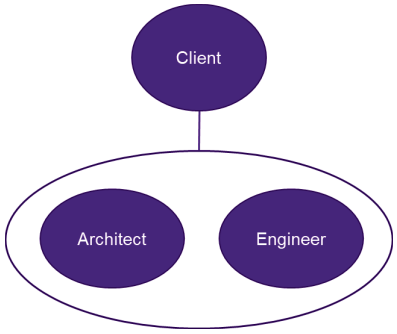
maintenance phase of the building. Nonetheless, with an active discussion between the actors, enough reassurance was produced to clear out doubts concerning for example different material choices and surface treatments. Overall, the client approved all the suggested decisions by the actor network after going through all the possible operational scenarios during the maintenance phase.



Picture 1: *Key actors in the design phase promoting circular economy targets*

Secondly, the architect and the engineer combined their resources during the planning phase of the project and the interviewee described the collaboration as a 50/50 relationship. However, the architect was the official project manager during the planning phase and took more responsibility for the finalized solutions. The engineer had a role to supplement the actor-network with technical capabilities that enabled the detailed level of planning and provided an additional understanding of the regulatory framework. In particular, the engineer had more understanding of acoustic and fire requirements that are key aspects in timber construction but the architect made sure that the surface materials matched the client's requirements. The interviewee summarized that experience in timber construction and collaboration with the engineer in previous projects enabled the providing of circular solutions for the sustainability targets set by the client.

Thirdly, innovative construction projects are typically perceived as high-risks and high-cost in comparison to conventional solutions. This was also a concern highlighted by the interviewee during the project. However, the project team was able to reach cost-effective results and reach the financial requirements for social housing. To meet the set financial requirements, the interviewee described that they focused resources in the early design phase on understanding how the project contractors should be tendered to reach an optimal outcome. The architect and the engineer came up with a

Table 4 *Activities, resources and actors promoting circular economy in the mid-rise timber construction design phase*

Activities	Resources	Actors
Sustainable material selection	Experience and specialization in timber construction and a circular economy in housing projects to optimize material selection and use with fire and acoustic requirements in mind	Architect, engineer
LCA	Understanding of the building component life spans, environmental impact, cost of their replacement and the possibility to replace them if needed. Collaboration with the client to communicate and ensure good quality building component life cycle performance	Architect, client
Maintenance planning for tenant turnovers	Understanding how wood material will behave under tenant use and agreeing on the surface material tolerance with the client	Architect, client
Design for disassembly and flexibility	Utilizing the spatial expertise of the architect and combining it with the technical understanding of engineers on how timber structures can be designed with mechanical joints	Architect, engineer
Design solutions that enable easy construction phase assembly	Designing the solutions with the tendering process in mind, market must have the operators to realize the design solutions	Engineer, architect
A structural system that enables good-quality moisture control in the building phase	The possibility to erect the building without moisture damage in the structures by using skeleton structure and taking care of façade elements' moisture control	Architect, engineer
Innovation during the design phase to develop solutions for circularity	Collaboration with client to ensure the functionality of new approaches and solutions. Enough financial understanding and resourcing in working with development projects	Client, architect, engineer

solution where the tendering was divided into three tenders, while conventional projects only use one main contractor. This enabled the actor-network to acquire more specialized contractors for the building phase that were able to produce cost-effective solutions. However, the required additional design work affected the architect's commission negatively. Overall, the case project was financially successful.

Finally, a more specific collection was produced from all the identified circularity promoting activities, resources, and the actor responsible for them (Table 4). The interviewee was able to describe how each identified circularity activity was combined with a specific resource to reach the set circularity targets described in Table 3. As a result, a description of how each actor can contribute to promoting a circular economy in the early design phase.

In the interview, it was also mentioned that it would be good to get the product manufacturers involved in the early design stage. It was also noted that this is usually difficult because the product manufacturers are typically selected based on tenders at a later design stage. However, this prompts us to discuss if the tendering and selection of manufacturers should be done earlier or if it would be possible to get product manufacturers involved in early planning by other means.

5 DISCUSSION

The case study analysis showed that it was possible to design a project that is contradicting the competition brief by introducing a new system though the brief clearly states that proven systems are preferred. However, the design team has successfully argued that their system is more in line with sustainability than conventional solutions. The used hybrid construction system is based on mechanical metal connectors that allow easy assembly and disassembly and it is the result of tight cooperation between architects and engineers. Though the system has not been used and proven to function well in advance, the joint effort of the architects and engineers is in line with the competition brief where it was claimed that interdisciplinary cooperations are highly appreciated.

The case study project represents design for disassembly (DfD) even though this was not directly required in the competition program. However, the client and the competition organisers could include DfD in the brief to promote material efficiency. DfD improves the possibilities of reusing the materials, as well as the flexibility of the project.

The strategies to promote a circular economy are many and some are easily measurable, which makes it easier to set targets in the project brief that assure circular measures. For example, if the goal is to use secondary materials, an amount of reused or recycled content can be defined in the project brief [8,27]. Setting a low carbon footprint or carbon balance in the brief would, besides promoting secondary materials, also promote the use of renewable and local materials because of their generally lower carbon footprints [8,28–30]. Setting carbon demands that include Module D (Benefits and loads beyond the system boundary) favour the use of bio-based materials such as timber (carbon storage) and DfD that allows easy reuse and value retention of components.

Whereas recycling targets and carbon goals increase the use of materials with low negative environmental impacts, material passports have been identified to promote circularity after deconstruction. Requiring materials passports means encompassing the life cycle of construction materials during the design phase, making it easier to design for reuse and disassembly and to plan the future of the materials in case of deconstruction [11,31]. Reversible design can also be promoted in the early project planning phase by requiring detailed demolition plans in the design phase and mechanical joints in construction.

Defining technical solutions precisely is challenging in the project planning phase, as it complicates the tendering that takes place later in the project. However, in the project planning phase, the pre-fabrication, modularity and repeatability, which have been identified to promote resource efficiency, can be determined to some extent.

Material efficiency can be promoted through technical design but also through high-quality architectural design. Well-designed buildings are more likely to be well taken care of, which prolongs the buildings' lifespan. Architectural quality can be increased by organizing architecture competitions and selecting the most promising plan and design teams. Additionally, designers can promote sustainability by preparing for possible future scenarios by designing buildings that can adapt. Adaptability or flexibility can be considered in the early project planning phase. In apartment buildings, this could be done by requiring plans for how to combine apartments vertically or horizontally, which was done by the architects in the studied case even though it was not required.

This study was based on only one case project. Therefore, the conclusions from this study cannot be generalized and assumed to be valid in all projects. To form a more generalized understanding of how different construction actor-networks can reach ambitious circularity targets a broader data collection and analysis is required. However, there are a limited amount of realized mid-rise timber projects that follow the key principles of a circular economy. In conclusion, the results of this paper should rather be read as indicative than absolute.

6 CONCLUSIONS

The studied case project showed various ways of promoting circular economy in mid-rise timber buildings. Many key aspects of a circular economy were already present in the early project planning phase. This paper set out to investigate how clients can include circularity in project briefs and how these can be met in the final project, who are the key actors to promote circularity in mid-rise timber projects and what resources are needed for the actors to deliver a circular construction project. The main findings are:

- The client can include targets steering towards circular solutions in the project planning phase by writing them into the project brief. Such targets include: flexibility, local and renewable

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materials, materials with low embodied energy, robustness against wear and tear, energy-efficiency, sustainability certificates, easy replaceability of components, simple structural solutions and common spaces.

- The identified key actors from the early design phase that are responsible for promoting circular economy are the client, the architects and the engineers.
- The client's role is more passive in the design phase in comparison to those of the architects and engineers but acts like the enabler of circular solutions
- Even though the client can include circularity in the project brief, a competent design team can exceed the targets and deliver more circular solutions
- When realising circular mid-rise timber buildings, previous collaboration between the architects and engineers, experiences with timber buildings and complex buildings, knowledge of LCA, and a deep understanding of circularity in construction are beneficial for the design team.

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REFERENCES

[1] Global ABC., IEA., UNEP. Towards a zero-emissions, efficient and resilient buildings and construction sector. 2019 Global Status report, 2019.

[2] UNEP. Sustainable Buildings and Climate initiative, 2009.

[3] IRP. Global Resources Outlook 2019: Natural Resources for the Future We Want, 2019.

[4] Circle Economy. The Circularity Gap Report: Closing the Circularity Gap in a 9% World. Circle Economy, 2019.

[5] Mishra A., Humpenöder F., Churkina G., Reyer CPO., Beier F., Bodirsky BL., et al. Land use change and carbon emissions of a transformation to timber cities. Nature Communications 13:4889, 2022.

[6] Ellen MacArthur Foundation. What is circular economy, n.d.

[7] Munaro MR., Tavares SF., Bragança L. The ecodesign methodologies to achieve buildings' deconstruction: A review and framework. Sustainable Production and Consumption 30:566–83, 2022.

[8] Kozminska U. Circular design: Reused materials and the future reuse of building elements in architecture. Process, challenges and case studies. IOP Conf Ser Earth Environ Sci, vol. 225, Institute of Physics Publishing, 2019, 2019.

[9] Eberhardt LCM., Birkved M., Birgisdottir H. Building design and construction strategies for a circular economy. Architectural Engineering and Design Management 18:93–113, 2022.

[10] Ellen MacArthur Foundation. Potential for Denmark as a Circular Economy. A Case Study from: Delivering the Circular Economy - A Toolkit for Policy Makers, 2015.

[11] Westerholm N. State of Play for in Europe Circular Built Environment, UN OPN SBC Programme, 2020.

[12] Basbagill J., Flager F., Lepech M., Fischer M. Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts. Building and Environment 60:81–92, 2013.

[13] Heravi A., Coffey V., Trigunarsyah B. Evaluating the level of stakeholder involvement during the project planning processes of building projects. International Journal of Project Management 33:985–97, 2015.

[14] Huovila P., Westerholm N. Circularity and Sustainability in the Construction Value Chain. IOP Conference Series: Earth and Environmental Science 1078:012004, 2022.

[15] Reike D., Vermeulen WJV., Witjes S. The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling 135:246–64, 2018.

[16] Hakansson H., Johanson J. A model of industrial networks. Industrial networks - a new view of reality, , 1992, p. 28–36, 1992.

[17] Håkansson H., Gadde L-E. Four decades of IMP research – the development of a research network. IMP Journal 12:6–36, 2018.

[18] Biem A., Caswell N. A value network model for strategic analysis, 2008.

[19] Barney J. Firm Resources and Sustained Competitive Advantage. Journal of Management 17:99–120, 1991.

[20] Möller K., Rajala A. Rise of strategic nets - New modes of value creation. Industrial Marketing Management 36:895–908, 2007.

[21] Håkansson H., Ford D. How should companies interact in business networks?, 2002.

[22] Yin RK. Applications of case study research, 2003.

[23] Gustafsson J., Gustafsson J. Single case studies vs. multiple case studies: A comparative study, 2017.

[24] Eisenhardt KM., Graebner ME. Theory Building from Cases: Opportunities and Challenges. vol. 50, 2007.

[25] Miles MB. Qualitative data analysis : a methods sourcebook. 4th edition. SAGELos Angeles, 2020.

[26] Knight A., Roddock L. Advanced research methods in the built environment. Wiley-BlackwellOxford, 2008.
[27] United Kingdom Green Building Council. Circular economy guidance for construction clients : How to practically apply circular economy, 2019.
[28] Asdrubali F., D'Alessandro F., Schiavoni S. A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies 4:1–17, 2015.
[29] Skullestad JL., Bohne RA., Lohne J. High-rise Timber Buildings as a Climate Change Mitigation Measure - A Comparative LCA of Structural System Alternatives. Energy Procedia 96:112–23, 2016.
[30] Takano A., Hughes M., Winter S. A multidisciplinary approach to sustainable building material selection: A case study in a Finnish context. Building and Environment 82:526–35, 2014.
[31] Høibye L., Sand H. Circular economy in the Nordic construction sector Identification and assessment of potential policy instruments that can accelerate a transition toward a circular economy, 2018.

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