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Industrial ecosystem renewal towards circularity to achieve the benefits of reuse - Learning from circular construction

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A R T I C L E I N F O

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A B S T R A C T

To enable an industry-level transition towards the circular economy, complementary companies and other actors from the focal industry sector, resembling an industrial ecosystem, can jointly increase circulation via reuse or recycling in the system. Although all involved actors must benefit from doing so if their engagement is to be secured, little is known about how industrial ecosystem renewal towards circularity creates benefits. Therefore, this study aims to contribute by applying ecosystem and circular industry development approaches to examine how industrial ecosystems change towards circularity, particularly in regard to the little-studied reuse principle, and identify the diverse benefits of an industry's shift towards circularity via reuse. Thus, this study examines changing industrial ecosystems in the construction industry which have high environmental impacts and focuses on the needed changes to the roles, interactions, and perceptions of ecosystem actors and the diverse benefits gained by increased reuse at company, industry, and societal levels. We conducted an extensive multiple-case study of two industrial ecosystems, namely pilot projects addressing concrete-element reuse, in Finland and Sweden and gathered extensive data covering over 20 interviews, over 18 months of ethnography, and over 300 documents. Our findings show that industrial ecosystems' renewal towards circularity requires changes in the ecosystem actors' roles (role expansions and emergence of new roles), interactions (communication, collaboration mindset, utilization of tools), and perceptions (understanding the value of circulated resources, design thinking, and change resistance to conformity). We found that such changes towards circularity generate benefits at the micro level to companies (direct business, competence, and work satisfaction benefits), at the meso level to the industry (environmental, competition, and industry feasibility benefits) and at the macro level to society (environment and employment benefits). Pragmatically, we provide insights and tools for development, business, and sustainability managers, industry associations, and policymakers seeking an increase in circular practices and principles among the industry sectors, involved companies, and surrounding society. Our study contributes to industry-level and sectoral circular economy transformation, reuse, circular construction, and ecosystem research.

1. Introduction

The circular economy (CE) aims to increase the efficient use of resources by promoting the adoption of closing-the-loop production patterns and maintaining the value of products, materials, and components through the principles of reduction, reuse, and recycling (Ghisellini et al., 2016; Geissdoerfer et al., 2017). Innovation drives the CE as multiple actors, including companies from different industries, cities, and universities, must collaborate to develop circular processes and products (Ingstrup et al., 2020; Engez et al., 2021)). Shifting to CE is a system-level phenomenon: Whole value chains, industries, and business ecosystems must transition towards circular principles (Aarikka-Stenroos et al., 2021; Kaipainen and Aarikka-Stenroos, 2022). Furthermore, as business environments become more complex, the concept of ecosystems is increasingly used to describe growing interdependencies among actors (Aarikka-Stenroos and Ritala, 2017). Although widely discussed in the management literature (e.g., Adner, 2017; Thomas and Autio, 2020), ecosystems have been little investigated in the CE context (Aarikka-Stenroos et al., 2021). Therefore, we need more understanding of how CE ecosystems – and, more

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specifically, industrial ecosystems – can renew to forward the CE and bring benefits to companies, industries, and society.

To date, we know little of how industries can increase circularity by implementing the reuse principle: The recycling principle dominates research and practice, although reducing and reusing would provide even more value if resource efficiency were improved (Ranta et al., 2018a,b). In direct reuse, products or components are used again as a whole for their original purpose; thus, the product or component value is preserved more resource-efficiently than in recycling (Ghisellini et al., 2016; Russell and Nasr, 2019). In reuse, the value creation stems from retaining the original value and functionality of products with minor repairs, while in recycling the original functionality of products is lost when they are processed back to material level (Hansen and Revellio, 2020). Hence, in reuse, some labor may be needed to turn used products or detached components back into functional products, while recycling requires high-energy inputs to process products back to materials (Ghisellini et al., 2016; Reike et al., 2018; Hansen and Revellio, 2020). More understanding is needed of what kind of actor group (i.e., ecosystem) can jointly enable reuse and renew industries to move towards more sustainable practices (Korhonen, 2007). Previous research also lacks insights on how supply chains within industrial ecosystems have to be reorganized to enable reuse (De Angelis et al., 2018; Farooque et al., 2019).

Previous research has presented some insights on the required changes when industries transition towards more circular practices regarding aspects such as culture, behavior, and mindset (Anastasiades et al., 2020; Hossain et al., 2020; van Langen et al., 2021; Ghisellini et al., 2018), socio-ethics (Inigo and Blok, 2019), roles within industries (Hagbert and Malmqvist, 2019), and relationships between society, economic systems, and the natural environment (Ghisellini et al., 2016). Based on existing research, we know that CE enables benefits on the micro, meso, and macro levels (Kirchherr et al., 2017; Anastasiades et al., 2020). In addition to providing environmental benefits (e.g., Hossain et al., 2020; van Langen et al., 2021; Ghisellini et al., 2018), CE can bring economic benefits through, among other innovations, new business models and opportunities (van Langen et al., 2021; Nußholz et al., 2020; Ranta et al., 2018a,b; Hossain et al., 2020; Ghisellini et al., 2018), improved customer value (Nußholz et al., 2020), and social benefits (van Langen et al., 2021). However, greater understanding is needed of the different changes required for industry renewal and the benefits of industry renewal towards CE on different levels.

When industries and sectors aim to transit and change towards more environmentally friendly and circular operations, industry-level efforts are needed (Ghisellini et al., 2016; Moktadir et al., 2018). Particularly environmentally burdensome industries, such as the construction and demolition sector (Ghisellini et al., 2018; Joensuu et al., 2020), textiles and leather (Fischer and Pascucci, 2017; Moktadir et al., 2018), and manufacturing (Lieder and Rashid, 2016), must initiate more industry-wide circular practices (Hagbert and Malmqvist, 2019). Previous research has highlighted the need for a meso-level approach when studying the construction industry (Anastasiades et al., 2020; Hossain et al., 2020). In this study, we complement the industry approach with the ecosystem approach, which has been increasingly applied when circularity is studied in system settings, the focus being on increasing circularity – via recycling, reuse, or reduction – in systems of actors and technologies (Aarikka-Stenroos et al., 2021). Industrial ecosystems are one type of CE ecosystem focusing on regional material flows (Aarikka-Stenroos et al., 2021). We chose to examine industrial ecosystems for reuse in the empirical setting of the construction industry as, given its material-oriented nature (Ghaffar et al., 2020) and high environmental impacts (De Wolf et al., 2020), even small improvements bring vast environmental benefits. The ecosystem approach is suited to studying the construction industry (Ghaffar et al., 2020; Wijewickrama et al., 2021), as innovation and change are needed on different levels to enable CE transition in a conservative industry (Guerra and Leite, 2021). The construction industry entails a diversity of business models, from services to products, which provide interesting settings for industrial ecosystem renewal.

To address the identified research gaps and achieve our research aim, we examine i) what changes are necessary within the industrial ecosystem's roles, interactions, and perceptions to enable benefits from reuse; and ii) what benefits arise from industry renewal towards circularity at different levels.

To meet our research aim, we conducted an extensive case study of how two industrial ecosystems changed and developed to implement the reuse principle due to the expected benefits and examined the ecosystems for concrete-element reuse in relation to the deconstruction of old buildings and reuse of detached building components in new buildings. The studied industrial ecosystem comprises two pilot projects from Finland and Sweden in which construction industry companies and public actors work together to enable concrete-element reuse within the ReCreate project (EU Horizon 2020 project).

We intend to contribute to research on CE ecosystems, circular construction, CE research, and research on industry-level CE-transformation. Our research provides a novel understanding of industrial ecosystems for reuse, focusing on changes in roles, interactions, and perceptions and the benefits they enable at different levels. We contribute to reuse-focused CE research by improving the understanding of the ecosystem needed to enable reuse. Our study was conducted in multi-actor settings in the construction industry, thus adding to the ecosystem and circular construction research.

2. Theoretical background

2.1. Industrial ecosystem approach to CE and reuse

An ecosystem in management research refers to an ecosystem of actors, rather than a natural ecosystem: an entity consisting of complementary actors taking varying roles linked through interdependencies (Thomas and Autio, 2020; Aarikka-Stenroos et al., 2021). Thus, we apply the ecosystem approach and recent research on the CE to understand industrial ecosystems' renewal towards circularity. We rely on the definition of the CE ecosystem proposed by Aarikka-Stenroos et al. (2021, p. 261), of "*communities of hierarchically independent, yet interdependent, heterogeneous sets of actors who collectively generate a sustainable ecosystem outcome.*" that can be further divided into different types of CE ecosystems, including industrial, business, and innovation ecosystems. As this study addresses industry circular renewal, we focus on industrial ecosystems, referring to *"regional communit(ies) of hierarchically independent, yet interdependent, heterogeneous set(s) of actors who sustainably produce industrial goods and services in symbiotic collaboration and resource use"* (Aarikka-Stenroos et al., 2021. p. 266).

The related terms, circular business ecosystem refers to interdependent and co-evolving sets of companies actualizing a circular value proposition by a company, the focus being on creating economical value (Aarikka-Stenroos and Ritala, 2017; see Adner, 2017; Aarikka-Stenroos et al., 2021), while the innovation ecosystem comprises a set of actors focusing on value creation out of new innovations (Autio & Thomas, 2014; Aarikka-Stenroos and Ritala, 2017; Aarikka-Stenroos et al., 2021). Thus, the business- and innovation ecosystems differ from the circular industrial ecosystem from the perspectives of focus (material, value, or knowledge flow) and intended outcome (Aarikka-Stenroos and Ritala, 2017; Aarikka-Stenroos et al., 2021), which are key elements of our research. We focus on the renewal of the industry, rather than the renewal of an individual company, and thus we use the concept of a circular industrial ecosystem instead of, e.g., a circular business ecosystem focusing on individual companies and their cooperation and value creation mechanisms. Therefore, we understand circular industrial ecosystems, as a diverse set of actors (including both public and private sector actors, e.g., companies, academia, cities, and associations) who work collectively across the industry to provide and produce sustainable goods and services, and aim for sustainable use of resources and materials (see also European Union, 2022).

The industrial ecosystem approach also binds together different companies' businesses, as industrial ecosystems have also been described as business-to-business recycling networks (Korhonen, 2001) and local or regional systems in which several industrial entities are actively involved (Lowe and Evans, 1995; Korhonen and Snäkin, 2005). An ideal industrial ecosystem optimizes energy and raw material consumption and minimizes waste production, and a by-product of one process is a resource for another (Frosch and Gallopoulos, 1989). Ayres and Ayres (2002) describe that such an ecosystem would operate in a closed loop of recycling and reuse without producing any waste. Thus, the concept of an industrial ecosystem has been related to the concept of industrial symbiosis where the focus is on the direct exchange of waste or by-products between companies (Tsvetkova and Gustafsson, 2012; Valkokari, 2015; Aarikka-Stenroos et al., 2021). However, reflecting on the Frosch & Gallopoulus, (1989) definition of industrial ecosystems, industrial ecosystems can contain industrial symbiosis but not all industrial symbioses can be seen as industrial ecosystems. Therefore, industrial ecosystems are diverse. Korhonen (2007, p. 53) also presents four principles of a sustainable industrial ecosystem – roundput, diversity, locality, and cooperation – to describe social, economic, and environmental benefits. Because the material and energy flows of an industrial ecosystem circulate within it, process control and management are impossible without cooperation between actors (Korhonen, 2007). Cooperation can also be seen as part of the principles of diversity (Korhonen, 2001), as ecosystem diversity requires close cooperation between actors such as companies, consumers, and public administrations (Korhonen, 2007), but it can also be seen as encouraging the exchange of by-products between companies, reducing business risks, and improving public image (Geng and Côté, 2007).

The CE transition has led industries to seek for environmentally and economically viable circular practices (Quaghebuer et al., 2013; Lieder and Rashid, 2016; Fischer and Pascucci, 2017; Moktadir et al., 2018; Smol et al., 2015), particularly for environmentally burdensome industries such as the construction industry (Ghisellini et al., 2016; Pomponi and Moncaster, 2017; Joensuu et al., 2020). Although most solutions focus on recycling (Haas et al., 2015; Ghisellini et al., 2016; Kirchherr et al., 2017; Ranta et al., 2018a,b), industry actors have sought other innovative ways to implement circularity, such as prevention and reuse (Lieder and Rashid, 2016; Milios et al., 2019; Joensuu et al., 2020). Industry-level pursuit of CE is also reflected in an ever-increasing number of academic publications (e.g., Urbinati et al., 2017; Geueke et al., 2018; Ghisellini et al., 2018; Saidani et al., 2019) and a growing interest in practice, as industry actors realize the inevitability of moving in a sustainable direction.

2.2. Pursuit of circularity in the construction industry through reuse of building components

The construction industry's material-oriented nature (e.g., Ghaffar et al., 2020), high economic (Adams et al., 2017; Ghisellini et al., 2018) and environmental impacts, such as waste and emission outputs, use of virgin resources, and consumption of energy (Ajayi et al., 2015; Ghisellini et al., 2018; De Wolf et al., 2020) make it a key industry in the transition toward circularity. However, in CE – and, in particular, in the context of the construction industry – recycling has been the most popular of the CE principles and its R-imperatives ranging from recycling and reuse to reduction (Ghisellini et al., 2016; Pomponi and Moncaster, 2017; Ranta et al., 2018a,b; Reike et al., 2018; Huang et al., 2018; Malmqvist et al., 2020); hence, less attention has been paid to reuse and reduce. For example, Guerra et al. (2021) highlighted how different actor groups utilize CE applications in the construction industry (e.g., through recovery, recycle, reduce, and reuse). According to their study, technology companies were most focused on recycling, contractors on reducing and recycling, consulting companies on reusing and reducing, and materials and assets marketplaces on reusing, a scenario identified by the authors as due to the existing structure of the actors' business models (Guerra et al., 2021).

Reuse has the potential to deliver both environmental (Zabek et al., 2017; Iuorio et al., 2019; Çimen, 2021) and economic (Stahel, 2016; Chileshe et al., 2018; Hopkinson et al., 2019) benefits. However, achieving the benefits of reuse and ensuring its uptake in the construction industry require innovation to overcome the barriers and challenges that have emerged. Rakhshan et al. (2020) identified that the barriers are mainly economic, technical, and social, such as rising costs, design challenges, meeting compliance requirements, finding means to dismantle intact, lack of demand, and negative perceptions. Thus, with reuse being a new approach in the construction industry (Rakhshan et al., 2020), and given the networked structure of the construction industry (Cheng et al., 2001), actors need to innovate together. As the construction industry is at an early stage of the move towards CE (Hossain and Ng, 2018) and the industry is renowned for its conservative outlook and high resistance to change (Kibert et al., 2000; Guerra and Leite, 2021), innovation and changes are needed at the micro (company; for example, new circular business models, technical solutions, change in mindset), meso (industry; e.g., change and innovations for collaboration between companies and stakeholders), and macro (society; e.g., changes in cultural and societal approaches and new innovations for providing economic incentives) levels (see e.g., Anastasiades et al., 2020; Hossain et al., 2020; Nußholz et al., 2020).

2.3. Theoretical synthesis and framework

We build on previous understanding of industrial ecosystems which highlight cooperation between companies in a B2B context in a direct waste and by-product exchange (Frosch and Gallopoulus, 1989; Korhonen, 2001) and call for system-level action to generate economic and environmental benefits (Tsvetkova and Gustafsson, 2012). Thus, CE ecosystems – and, more specifically, industrial ecosystems – offer a good framework for a CE approach that focuses on the most efficient loops of materials and resources and cooperation between actors (Ghisellini et al., 2016; Geissdoerfer et al., 2017). Therefore, we examine which ecosystem actors are required for reuse and how their roles, interactions, and perceptions change when new ways of working are adopted. These changes come with challenges but also benefits for individual companies, the industry, and society more broadly.

With a focus on reuse rather than recycling, this study seeks to understand the positive and negative impacts of the transition to the CE, as the CE is a system-level phenomenon that requires changes on company, value chain, industry, and ecosystem levels (Aarikka-Stenroos et al., 2021; Kaipainen and Aarikka-Stenroos, 2022). According to previous research, we assume that changes are needed in roles, interactions, and perceptions (e.g., Ghisellini et al., 2016; Hagbert and Malmqvist, 2019; van Langen et al., 2021). Previous understanding indicates that the benefits of the CE seem to be distributed at micro, meso, and macro levels (Kirchherr et al., 2017; Anastasiades et al., 2020). Fig. 1illustrates the theoretical framework depicting the industrial ecosystem change to enable the benefits of CE on different levels.

3. Methodology

3.1. Research design and cases

We selected an extensive qualitative multiple-case study research strategy for our study of two industrial ecosystems for circularity because this approach enables empirical investigation of contemporary phenomena within their real-life contexts (Robson, 2002; Yin, 2009), here of industrial ecosystem actors and their roles and interactions during a pilot project. Case selection was purposive and followed theoretical sampling (Eisenhardt, 1989), implying that the selected cases are particularly suitable for the research aim. Our research is based

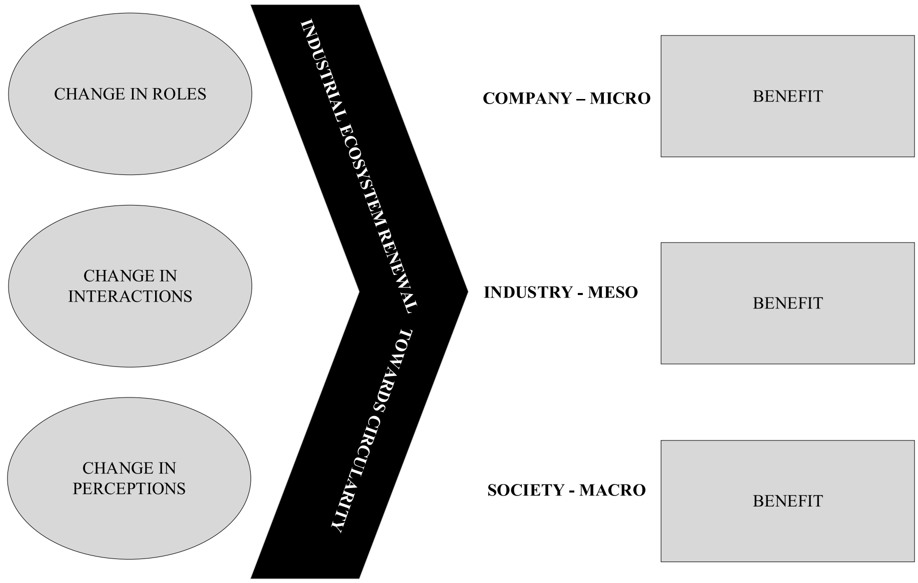

Fig. 1. The theoretical framework for the study.

on the EU-funded ReCreate project initiated in March 2021, which studies the reuse of precast concrete elements through pilot projects in Finland, Sweden, Germany, and the Netherlands. Each of these country pilot projects includes a deconstruction and the construction of a new building reusing the detached concrete elements. This study examines the pilot projects in Finland and Sweden (hereafter, FPP and SPP), due to their similar institutional contexts, to identify similarities and differences among the changes within the industrial ecosystems and the resulting benefits. Both cases display the necessary roles in the ecosystem and cover a full industrial process of concrete reuse, enabling examination of the entire process across multiple actors. The cases focus on different phases of the building process, enabling extensive empirical understanding of the process and the industrial ecosystems formed around it.

3.2. Data collection and analysis

Our research data consist of primary sources, including semi-structured interviews, observations, and ethnographic follow-up, and secondary sources, including media data and reports (see Table 1). Observation and ethnographic follow-up were the most important data collection methods and were undertaken from the beginning of the project in early 2021. The interviews gave us an extensive overview of the roles, tasks, challenges of individual actors, and direction of the development of the construction industry, while observation and ethnographic follow-up gave us a more comprehensive understanding of the ecosystem in terms of the linkages between different actors, their interaction, and changes in roles, interactions, and perceptions. Moreover, through the interviews we gained insights into micro- and meso-level issues, whereas through observations and ethnographic follow-up we were more able to identify meso- and macro-level issues regarding, for example, legislation affecting the whole industry, complementary actors needed to enable concrete-element reuse, and EU-level practices of concrete-element reuse. The interviewees were chosen as they play central roles in the pilot projects and thus provided the most relevant expertise for the research objectives.

We used an abductive reasoning process to analyze the data and theorize from the cases. We used the ecosystem literature to map the ecosystems, taking a somewhat deductive approach, while a data-driven thematic analysis undertaken in a more inductive manner provided findings in regard to changes in the ecosystems and benefits gained. As an example of our thematic and content analysis (Mayring, 2004), one interviewee commented *"we help in everything we can, and we learn from it at the same time. Because there are no clear roles [in concrete element reuse], unlike in conventional construction"* (architect). This comment was interpreted to help explain the role changes of the ecosystem actors. We initiated the data analysis with a *within-case* analysis to map both ecosystems separately and identify the changes and benefits gained within each. After first analyzing the cases separately, we compared them through a *cross-case* analysis which then triggered new rounds of within-case analysis. Through multiple analytical iterations between within- and cross-cases, including country-context comparisons, we finalized our theoretical framework and synthesized our findings.

The quality of the analysis was ensured by triangulation using multiple tactics and tools. We analyzed the data and wrote the results with an iterative process in which the research teams from Finland and Sweden worked in turns on the data analysis. Firstly, the researchers from Finland and Sweden analyzed the cases individually; then, we compared our interpretations and discussed the differences between the cases and compared them. This iterative process resulted in strong researcher triangulation and trustworthiness as there was a deep understanding of the institutional contexts within our research team. Atlas.ti and Excel were principally used to process and analyze the collected data. Diverse data types collected from multiple sources and by multiple researchers further improved data triangulation and trustworthiness (see Flick, 2004).

4. Results

The results section focuses first on the FPP (Section 4.1), then the SPP (Section 4.2). For both cases, we explain the ecosystem actors, particular characteristics, and changes within the industrial ecosystems compared to conventional construction regarding roles, interactions, and perceptions. We also present the benefits these changes bring at company, industry, and societal levels.

4.1. Planned industrial ecosystem – FPP

Regarding **ecosystem actors** for concrete-element reuse we found that the FPP industrial ecosystem (see Fig. 2) comprises multiple construction, demolition, manufacturing, architecture, and engineering companies, the city of Tampere, particularly the construction supervision and CE coordinator, and Tampere University. The companies are in charge of operational tasks, including demolition planning,

Table 1
Data types, descriptions, and role in analysis.

Data types	Description of the data		Role in analysis
	Finland	Sweden	
Semi-structured interviews with pilot project key actors	**Nine individual interviews:** Business development manager in a construction company (5/2021) Chief technology officer in concrete-element manufacturing company (7/2021) and (5/2022) Business development manager in (structural) design & consulting company (8/2021) Site manager in demolition company (9/2021) Project manager in demolition company (4/2022) Owner/architect in architectural design office (9/2021) and (4/2022) Senior research fellow at a university (10/2021) **Four group interviews, with**: Business development manager + project manager in a construction company (10/2021) and (5/2022) Manager of housing and development + project manager/specialist in city organization (10/2021) Unit manager, project manager, and department manager in (structural) design & consulting company (5/2022)	**Two individual interviews:** Associate Professor X at university (10/2021) Associate Professor Y at university (5/2022) **Four group interviews, with:** Associate professors at university (2) + researcher (10/2021) Housing company - managers (2) (10/2021) Concrete element manufacturer - managers (2) (10/2021) and (4/2022)	Individual actor interviews indicated individual actors' roles, tasks, interactions with others, and prejudices in regard to change compared to conventional construction projects in the industrial ecosystem.
Semi-structured interviews with other industry representatives	**Two individual interviews:** Manager in construction engineering company (7/2021) Manager in concrete industry organization (8/2021)		The complementary interviews broadened the understanding of what needs to be done differently to enable the reuse of precast concrete elements. The interviewees had previous experience of the reuse of precast concrete elements.
Observation, ethnographic follow-up	Attending country-cluster meetings involving all ecosystem actors of the FPP (15) Attending country-cluster demolition planning meetings (8) Visiting the demolition pilot site in Finland (1)	Attending country-cluster meetings involving all ecosystem actors of the SPP (15) Visiting a similar reference demolition pilot site in Sweden (1) Visiting the pilot building in Sweden (1)	Observation of meetings and discussions allowed us to identify actor interdependencies and interactions, particularly micro- (company) and macro- (industry) level benefits such as direct business benefits for companies and environmental benefits for the industry.
Minutes and reports	Project plans (2) Meeting memos (22) (4/2021–9/2022)	Project plans (1) Meeting memos (21) (4/2021–9/2022)	Analyzing meeting memos and project plans strengthened the findings in regard to changes (such as the differences in demolition planning and planning the new building) identified from interviews, observation, and ethnographic follow-up.
Secondary data, e.g., media data, company reports	Systematic LexisNexis search with relevant keywords (FI = 129, e.g., news, annual reports, blog posts); relevant master's thesis for the context (3)	Systematic LexisNexis search with relevant keywords (SWE = 124, e.g., news, annual reports, blog posts)	By analyzing secondary data, we gained a better understanding of the country context of the pilot projects and the general attitude towards the reuse of precast concrete elements, such as the kinds of news published on reuse in the media in general and by the companies.

deconstruction, logistics, quality assurance, redesign, and construction of new building(s), whereas the city supports regulatory tasks. The local university acts as coordinator and research organization, as the project received EU funding to study the environmental, business, and social acceptability aspects of concrete-element reuse and, partially, the costs of the city and collaborating companies. We observed that many other critical supporting actors also contribute to or determine the reuse of concrete elements and the pilot project but do not receive funding or are not directly involved in the project. Authorities supporting the standardization of reusable concrete elements or deconstruction equipment (e.g., ministries and agencies) are crucial in promoting the reuse of concrete elements: As one construction company manager commented, "*guidance from public authorities is needed as change won't happen on its own.*" Other important supporting actors include associations for the communication and visibility of the project (e.g., GBC Finland) and subcontractors supporting operational tasks such as quality assurance or providing equipment (laboratories, lifting equipment manufacturing companies, equipment suppliers).

Particular characteristics of the FPP include the central location of the deconstruction, careful planning of aspects such as the logistics and work safety of the deconstruction, and reusing elements in multiple buildings. The FPP concerns an old office building located in the center of Tampere, planned for deconstruction in late 2022, and reuse of carefully detached concrete elements (beams, columns, hollow-core slabs) in several new buildings with a high utilization rate, such as offices or residential buildings. Neither new building types nor the locations where the detached elements will be reused have yet been defined in project meetings. From the risk diversification perspective, as the whole concept is new, the detached and refurbished concrete elements are planned to be divided across several sites. Negotiations on building types, sites, and locations remain ongoing in late 2022. Since concrete-element reuse is a new approach and concept for the Finnish construction industry, multiple private- and public-sector actors, from deconstruction to (re)building, began collaborating from the planning phase in 2018 to combine expertise and knowledge. Innovating more circular construction practices also aligns with the sustainability development goals of Tampere.

When the FPP officially launched in March 2021, the first task was to select an old building with applicable concrete elements for deconstruction. The donor building was selected from the construction

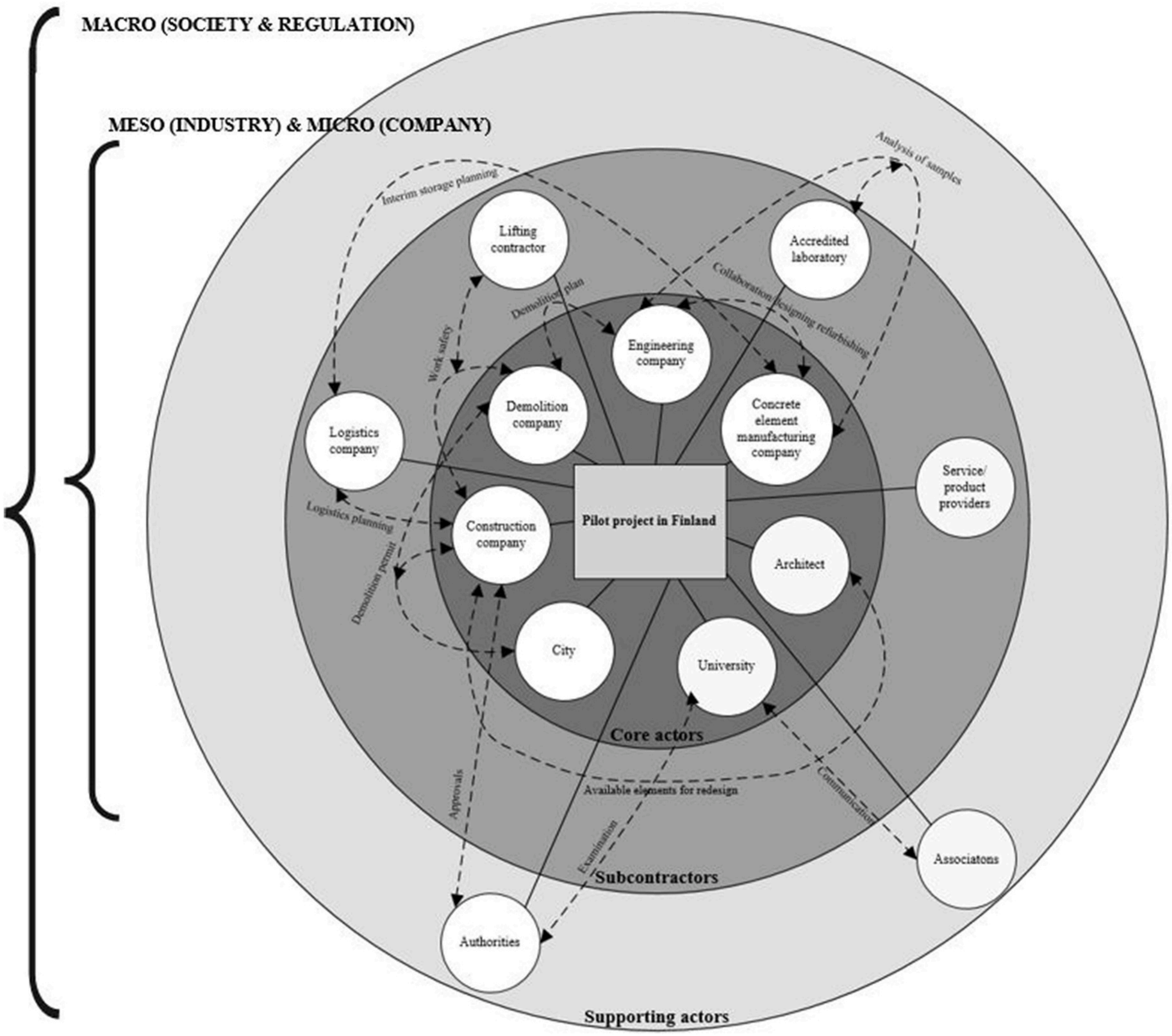

Fig. 2. The industrial ecosystem for the FPP displaying roles, tasks, and interactions.

company's demolition portfolio due to its suitability regarding schedule, location, building, and other components. Later in 2021, the focus moved to identifying suitable building components for reuse, and discussions with all ecosystem actors underlined the need to plan and perform deconstruction carefully as the FPP presented a new challenge and new way of working for everyone; work safety was stressed in project meetings. Design and digitalization were identified as crucial to concrete-element reuse, so a 3D inventory model and condition survey were performed. Demolition planning meetings ran from late 2021 until deconstruction began to ensure consideration of all aspects and scenarios and readiness of separate sub-plans (e.g., logistics, dust control, moisture management, work safety, and fall protection) before the deconstruction work begins in late 2022, when the necessary permits are ready. After deconstruction, the focus will shift to logistics and data-gathering as the elements will be transported to intermediate storage, marked (possibly radio-frequency identification (RFID)), tested, and, if necessary, refurbished. Currently, as requested by the construction company, in the FPP the plan is to utilize the reusable elements in several locations in Finland. The design of the new building(s) can be initiated in cooperation with the architect and engineering and construction companies once they know which site(s) will receive the reusable elements. The architect leads the design process, which includes the technical designers in charge of the electrical, automation as well as heating, ventilation, and air conditioning (HVAC) designs.

Various design options to use the detached elements have been considered. The architect began exploring different aesthetic possibilities (e.g., combining detached elements and wood) early on. Uncertainties about the future of the FPP include the reuse locations for the detached elements and the exact construction schedules for the new building(s) reusing them. At the outset, the architect described the challenge of choosing the reuse locations by observing that *"different element typologies and characteristics have been used in different eras, which will influence the possibilities for further reuse."* However, after the old building is deconstructed and the new one(s) designed, the construction phase can begin, with detached elements transported to the new site(s) and construction performed according to the redesign plans. Under the initial plan, the detached elements are tracked or followed, for example by RFID, in the new building. The ecosystem actors also gather and process learnings throughout the project by collecting best practices and future exploitation plans for companies and cities regarding both the economic and environmental aspects of concrete-element reuse. The aim is to complete the pilot project in 2025.

The **changes in the industrial ecosystem compared to conventional construction** occur at micro, meso and macro levels. Transitioning from conventional construction to reusing concrete elements requires changes in *roles*, *interactions* between ecosystem actors, and *perceptions* within the industrial ecosystem. The FPP demonstrates a number of major *role changes* for ecosystem actors as well as smaller role adjustments. We observed that the concrete element manufacturer expands their conventional manufacturing role to participating in demolition planning and marking, storing, and refurbishing the detached elements, while the engineering company expands their conventional structural designer role to participating in most phases of the reuse project. These role changes enable the companies to develop new skills and competences and expand into new areas *(company benefit)*. In the deconstruction phase, the demolition company has the central role; however, specific expertise and supporting knowledge are needed from others. In deconstruction, the elements are detached whole, requiring innovative solutions, ways of working, and applications of existing knowledge and expertise, boosting the competence development of companies and the ecosystem *(company and industry benefit)*. Thus, role expansions during demolition planning and deconstruction from ecosystem actors are needed. The engineering company focuses on work safety planning and the initial demolition planning together with the demolition company. The concrete-element manufacturing company provides knowledge of joints and elements used in the building and expertise on element lifting. The construction company supports deconstruction planning and implementation with overall expertise and knowledge from previous sites and this specific site and contributes to work safety issues because it is responsible for work safety on its site. The demolition company advices on feasibility and cost-efficiency and conducts the actual deconstruction work, supported by knowledge and work from others, including the lifting equipment manufacturer, university, authorities, element lifting company, and logistics operators. These new practices and the need for new actors can boost collaboration and open communication within the construction industry *(company and industry benefit)*. However, ecosystem actors also see challenges in turning concrete-element reuse into a profitable business. The interviewee from the concrete-element manufacturing company reflected that *"the biggest challenge is probably how to make it [concrete-element reuse] a feasible business as it requires quite strong guidance through legislation or the development of the calculation of these environmental values.* A manager from the construction company pondered on the challenges: "*We have no existing supply – and there is no demand yet – we have to build the [market] needs here [for concrete element reuse]."*

Interaction changes between the ecosystem actors are a prerequisite to enable the reuse of concrete elements. Firstly, the ecosystem actors had to adopt an open and inclusive communication style for the planning process to enable the development of innovative approaches and solutions to deconstruction and reuse *(company and industry benefit)*. Digital tools and technologies are used to improve information flow and open communication between companies *(company benefit)*. Initial discussions on how to identify reusable components revealed that design and digitalization constitute the core of concrete element reuse; thus, in September 2021, the architect and engineering company joined forces to create an inventory 3D model of the old building listing element types and basic dimensions, while the engineering company carried out a condition survey in collaboration with an accredited laboratory. We observed that the digital building information model has enhanced open collaboration for deconstruction and work safety planning as well as the redesign process. Utilizing digital tools and technologies in new ways and for new purposes boosts the digitalization of the construction industry *(industry benefit)*.

Collaborative attitudes and open communication have also been important for demolition planning. Initially, the demolition planning meetings entailed only the engineering, demolition, and construction companies, but they soon realized that more actors needed to be engaged. Therefore, the concrete-element manufacturing company and researchers from different disciplines joined demolition planning meetings in late 2021. Discussions in the initiation phase, particularly contributions from the construction company, emphasized the risks of the planned deconstruction (e.g., work safety) as workers had to detach elements manually inside the building instead of through conventional demolition. As demolition planning proceeded, the ecosystem understood that other supporting actors (element lifting company, equipment manufacturer, safety agency to approve new lifting equipment and use of deconstructed elements) were relevant to the deconstruction process. The industrial ecosystem also needed actors not required in conventional construction (e.g., lifting equipment manufacturer), which changes the ecosystem constellation and interactions. Close communication between all parties during the deconstruction phase is needed as the demolition company has to adopt new ways of working to detach the concrete elements intact. The FPP also demonstrates stronger interaction with public authorities than conventional construction projects: The city representative was actively involved early on, and the City of Tampere is interested in supporting CE transition in the region. Close interaction with public actors during the pilot project can enhance collaboration between the construction industry and public actors *(industry benefit)*.

Perception changes of building component reuse are important in adopting new innovations and solutions. All ecosystem actors must understand the innovative approach to reusing and treating the elements accordingly. One actor not understanding the value of the elements can destroy the value for everyone: After the demolition company has detached the elements, for example, the logistics company can destroy their value during transportation by handling them as waste. Regarding planning for deconstruction, new perceptions towards sub-plans are needed as the sub-plans for deconstruction differ from those for conventional demolition. The moisture management planning ensures that the elements are fit for reuse. The central location of the site and its minimal intermediate storage space must be considered and special attention paid to logistics planning and smooth operation. The redesign process is very different for the architects and structural designer, who, when using reused elements, must work with predetermined components instead of starting from scratch. Doing so requires a new way of thinking and new skills and results in competence development for architects and designers *(company benefit)*. A manager from the structural design company pondered the challenges of redesign thus: *"From a structural designer's point of view, it is a real challenge – it completely turns around the thinking process as they have to accept the qualities [of the detached components] and work with them – it changes the structural designer's way of thinking a lot."*

During the pilot project the aim is to identify and test new digital tools and search for new utilization areas for existing tools that could benefit the reuse process. Doing so, however, requires removing prejudices and changing perceptions. For example, the demolition company was hesitant about the benefits of utilizing digital modeling for deconstruction planning. To gain social acceptability and regulatory support, the ecosystem actors work to reduce resistance to change regarding the reuse of building components, which can also enhance material reuse on the societal level *(society benefit)* (e.g., the construction company considers its marketing approaches and media visibility). Moreover, concrete-element reuse changes the competitive dynamics within the construction industry, as other companies will likely develop reuse practices following the forerunners *(industry benefit)*. New ways of working raise caution among authorities. Thus, proving that the reuse of concrete elements is viable and safe will enable positive perceptions and regulatory support, enhancing consumer perceptions of the desirability of new buildings reusing concrete elements. Some interviewees also pondered on potential taxation incentives to turn concrete-element reuse into a profitable business. However, as innovative practices are new approaches for regulators as well, the latter do not have ready-made solutions for the new legislative questions arising. Hence, we observed that the regulatory processes in Finland (e.g., clarifying whether CE marking is needed for the detached elements) have slowed the progress of the FPP significantly compared to the pilot projects in other countries (namely Sweden, Germany, and the Netherlands).

4.2. Evolving industrial ecosystem – SPP

Regarding **ecosystem actors** for concrete-element reuse, we found that the core actors of the SPP ecosystem are the university, housing company, and manufacturing company (see Fig. 3). The core actors were in charge of the main operational tasks, such as designing the pilot building and finding a suitable plot for it to be constructed on, finding the reusable elements, and coordinating the building process. In addition to the key actors in the SPP, we identified so-called supporting actors that contributed to the success of the pilot project, including the municipal administrations responsible for the building permit process, detail designers (largely working in-house in the construction company), the construction company in charge of constructing the pilot building, the research institute handling the testing of precast concrete samples, and the owners and demolition companies of the various donor buildings. A reference R&D project, Återhus,[1] also investigated the potential of reusing building frames in Sweden and provided valuable knowledge, ideas, and inspiration.

We identified as **particular characteristics of the SPP** that the reused elements came from multiple donors, the pilot building (a pavilion) was small in size, no significant regulatory challenges emerged (e.g., CE marking of reusable elements, unlike in the FPP), and the number of actors involved was small. The SPP's objective was to construct a pilot building, a pavilion, which was completed in April 2022 and was part of an international housing fair in Helsingborg, southern Sweden, during May and June 2022. It was built to house an exhibition to demonstrate the reuse of construction materials in a new building.

In spring 2021, the housing company selected a site for the SPP in a residential area where an old preschool was to be deconstructed. After deconstruction in February 2022, the concrete base was saved for the pilot building, and additional components were identified for reuse and stored nearby. However, the preschool building had no prefabricated concrete elements to be saved. The original idea was to partly construct the pilot building from several precast concrete walls saved during an earlier demolition nearby, which had been detached and partially reconditioned by a subcontracted demolition company then transported to intermediate storage. During deconstruction and intermediate storage, some elements were lost and damaged. The loss and degradation of deconstructed elements was found to present a major challenge to carrying out the pilot project on schedule. We observed during project meetings and interviews that the breakage and loss of the elements was linked to the attitude of treating dismantled materials as waste. For example, the housing company stated in interview: "*We have an idea why it went like this, and it's that it's a little bit of this perspective that what's recycled or what's in the demolition waste that anybody can take, it's okay to pick it up, because you think nobody wants it, and it doesn't matter how you handle it. I think that's what's happened with our concrete elements. For example, someone has wondered why these elements are here and moved them carelessly, causing some to break and some to be lost.*" Thus, the housing company and architects at the university investigated whether the damaged elements could be cut and still reused, as there were too few undamaged elements to construct the pilot building. Given the tight schedule, finding suitable donor buildings was challenging, and while other precast elements were sought, it was doubtful that enough time remained for the design, building permit application, and actual construction. Initial proposals to highlight the benefits of reusing precast concrete elements had to be abandoned. Numerous questions were actually solved during the construction phase through continuous collaboration between the designers and other main actors.

An industrial building undergoing demolition in Helsingborg was found to be suitable, and concrete columns within it were deconstructed, refurbished, and incorporated into the pilot building design. The pilot also used some factory-rejected hollow-core slab elements from the concrete element manufacturer. The SPP construction materials thus had different origins, with donor buildings in different locations and deconstructed at different times. As a result, the required number of reusable elements was found, and the housing company was able to apply for a building permit, which made it possible to complete the pilot building on time.

The changes in the industrial ecosystem from conventional construction occurred at micro, meso, and macro levels. As the approach was relatively new for the actors involved in the SPP – indeed, for the whole industry – adaptation was necessary as the *roles* of ecosystem actors, *interactions* between them, and *perceptions* within the industry changed.

Role changes were imperative, as traditional roles and divisions of tasks did not cover all the necessary areas, so existing ecosystem actors (or emerging new ones) had to cover the missing roles. An interviewee from the university stated: "*We need to understand how existing actors intertwine and find solutions that work with potential new actors and new partners that do not yet exist but may emerge in the future to add value.*" Given the small number of key ecosystem actors involved in the SPP, we found that ecosystem actors needed to expand their own roles, enabling companies to develop new skills and competences and expand into new areas (*company benefit*). An interviewee from the university also identified opportunities for new actors: "*Just like with old houses, there's always a carpenter who understands how the structures work, for example coming into an old house with a wooden door that won't close because it's crooked and twisted. In a normal project they would throw the door away and put a new door in its place, but to preserve the door they called in 'Gunnar,' who came in, looked at the door, and fixed the situation without needing a new door. To do that with concrete elements, someone has to understand how they work and be able to fix them, that is, turning a new actor or extending the role of an existing actor into a 'Gunnar' in concrete.*"

Due to the small number of core actors in the SPP, we found that the role of the concrete element manufacturer, university, housing company, and construction company differed significantly from those played in a conventional construction project. For example, the concrete element manufacturer participated in planning, designing, and constructing the pilot building by providing expertise on solving problems related to reusing concrete elements, thus acquiring competences and new skills, potentially leading to new business opportunities (*company benefit*). Since the SPP did not involve an architect company, the university played the role of a traditional architect, being primarily responsible for the design and digital model of the pilot building but also coordinating the whole project together with the concrete element manufacturer and housing company. The construction company was jointly responsible for the construction of the pilot building and technical design alongside the concrete element manufacturer and university. It was identified that the construction company's use of in-house design expertise developed their CE know-how and competence, which will be of benefit to them in future tendering situations (*company benefit*). The housing company, on the other hand, was responsible for finding a suitable pilot site, applying for a building permit, and representing the client's point of view. Thus, the housing company gained knowledge of use in, for example, future decision-making to build sustainable and circular buildings. The know-how will also help the housing company and city achieve their sustainability and climate goals as it was identified that the SPP deepened their understanding of how to manage new and innovative projects (*company benefit*). We also found that the drive by the housing company and city as part of the SPP to find more sustainable practices contributed to the importance and dignity felt by employees as they contribute to more sustainable solutions, resulting in increased efficiency of the company (and more broadly the industry) through increased job satisfaction (*company and industry benefit*). In addition, we found that actors' active participation in solving the challenges faced (e.g., finding reusable concrete elements, dealing with a tight schedule) in the SPP, as a consequence of which their roles and responsibilities were largely assigned as the SPP progressed, boosted their collaboration, open communication, and joint problem-solving skills (*company and industry benefit*).

We observed that *interaction changes* resulted from the changes and

[1] https://aterhus.nu/.

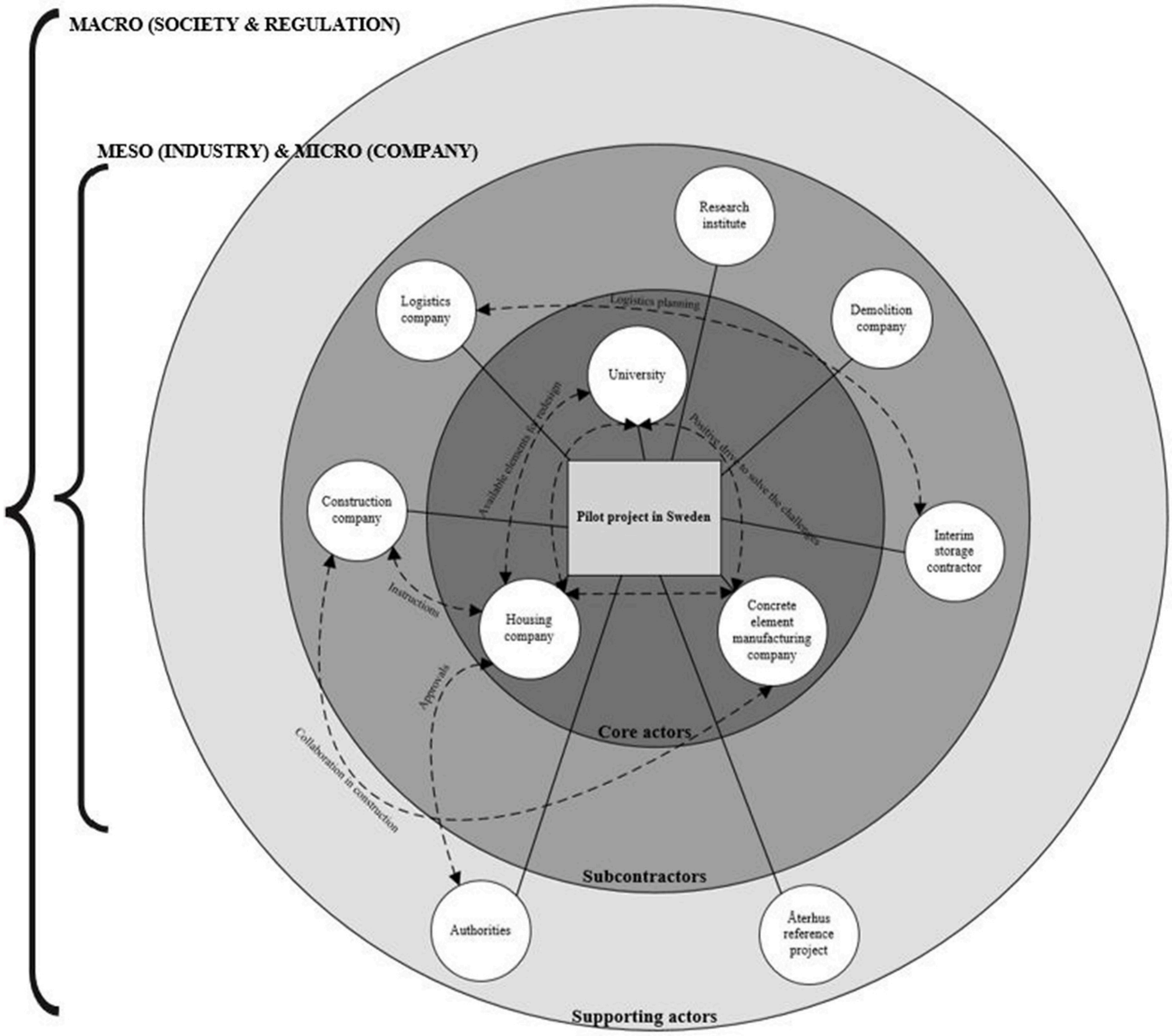

Fig. 3. The ecosystem for the SPP displaying the roles, tasks, and interactions.

expansions of the roles of ecosystem actors. The success of the SPP was principally based on the positive and cooperative attitude of the ecosystem actors, which boosted collaboration and open communication among participating companies and, more broadly, benefitted the whole construction industry (*company and industry benefit*). Although the challenges faced in the pilot project were overcome with a positive and cooperative attitude, the housing company representatives reflected that "*there are many challenges, especially how to draw the line so that every actor knows what they are responsible for. For example, who does what? Who is financially responsible for what?*" Unlike in conventional construction projects, we learned that the actors did not have only one area of responsibility; rather, they had a sense of a strong common goal and supported each other to succeed. For example, all actors were involved in finding suitable elements, whether by identifying sites to be demolished or potential donors, looking for factory-rejected elements, or offering demolition sites as donor buildings. The multiple origins of the elements and tight schedule also raised challenges for the design work, and thus the university, as architect and hence responsible for the design, received help from other ecosystem actors through comments, provision of detailed information within their own spheres, development of new ideas, and offers of expertise. In addition, we identified that a key interaction change is that all ecosystem actors are aware of what is considered valuable, which is why it is essential to communicate the value of deconstructed elements to all ecosystem actors so such elements are treated as valuable products, not waste. Therefore, the relevant planning requires special attention, and ecosystem actors must jointly consider how the elements will be transported, lifted, and stored. In the SPP, the housing company interacted extensively with other ecosystem actors, strongly influencing what was wanted from the pilot building, where it would be located, and where the necessary intermediate storage areas were, communicating with the authorities about building permits and discussing implementation details with the construction company and concrete element manufacturer. Most interactions regarding design and construction occurred between the construction company and concrete element manufacturer, who jointly bore most of the responsibility for implementation, but the housing company and university both offered new ideas and alternative perspectives.

Perception changes are inevitable as the actors, ecosystem, and industry shift towards more sustainable practices. We observed that the main change in perception identified was a change in mindset, namely that the deconstructed elements were seen as valuable resources by each ecosystem actor and not as waste, which would prevent loss and damage being sustained by the elements during transport or storage. The second key change in perceptions was the desire of companies and cities to work towards more sustainable solutions and provide more sustainable services for customers. Therefore, the shift towards sustainability drives companies and cities to think about new approaches and solutions; the City of Helsingborg and Helsingborg housing company, for example, were keen to develop sustainable and more climate-friendly solutions to become one of Sweden's leading cities in sustainability. Companies, such as the concrete element manufacturer, also expressed interest in participating to develop competitive advantage in sustainability and the CE. Through interviews and observation, we identified that the need for the reuse of precast concrete elements emerges mostly from environmental perspectives, such as reducing emissions and using fewer natural resources (*industry and society benefit*). On the other hand, there was greater skepticism about perceptions of the business potential. It was recognized that it might generate image benefit from more sustainable practices and, possibly, profitable business and new business opportunities in the future (*company benefit*); however, some of the SPP actors perceived that demolition volumes in Sweden were too low to develop the reuse of concrete elements into a profitable business. Rather, being at the forefront of sustainability transitions by adapting, learning, and being the first to change has the potential to provide a competitive advantage in the future, even if it does not yet bring direct economic benefits (*company benefit*). In addition, interviews and observation revealed that the creation of a profitable and scalable business reusing concrete elements would require regulatory support, such as tax incentives.

5. Discussion: case comparison and synthesis of the results

The FPP and SPP differ in ecosystem composition, as well as role, interaction, and perception changes within ecosystems, reflecting the different project flows and actor settings. The transition from conventional construction to reusing building components could benefit individual companies, the entire construction industry, and society more broadly. These benefits appear similar in the different industrial ecosystems of Finland and Sweden. Table 2 summarizes the changes and benefits of increased circularity of industrial ecosystems.

Benefits for companies include the image benefits gained from the forerunner status of applying innovative circular methods for demolition and construction. As forerunners, companies may benefit from the changing regulatory environment towards sustainability requirements, potentially increasing profitability and providing business advantages. Reusing concrete elements provides new business opportunities for companies or even the emergence of new companies. For example, the concrete element manufacturer could move their business model more towards the second-hand market, refurbish concrete elements, or even utilize factory rejects, as in the SPP. Also, detaching the concrete elements intact instead of conventional demolition provides a new business model for the demolition company. However, for such opportunities to materialize, other companies must accept and be ready to use the new products and services. Thus, the prerequisite for new business opportunities is that industrial ecosystems adapt to the new practices which enable them. The construction company may save costs by buying reused elements at a discount or reusing concrete components from their own demolition sites, as in the FPP. It may also be able to justify increasing price-per-square-meter for new buildings to customers by the high sustainability and circularity in their construction. However, some, or even most, customers may not be willing to pay a premium for the circular solutions applied, and thus some regulatory support (e.g., tax incentives or legislation to enforce circularity in construction) may be needed to make concrete-element reuse a profitable business. The new and innovative approach to construction enables the creation of new competences and expansion to new business areas for the engineering company, demolition company, and architect. Companies participating in the reuse of concrete elements can also benefit indirectly (e.g., in customer acquisition) through sustainability branding. Moreover, participating companies identified and utilized useful digital tools and technologies which enhance work safety and efficiency and may reduce the laboriousness of work processes, increasing both profitability and scalability. Job satisfaction improves as employees can work in a more sustainable way, increasing their engagement and thus improving efficiency.

Benefits for the construction industry arise from the transition towards

Table 2
Summary of changes and benefits of increased circularity of industrial ecosystems.

	Finland: Planned industrial ecosystem	Sweden: Evolving industrial ecosystem	Insights on changes and benefit types on different levels with examples
	Changes		
Role changes	- Companies' role expansions to new areas	- Major role expansions (e.g., concrete element manufacturer took part in every phase of the pilot project) for ecosystem actors	**Existing roles expand:** The ecosystem composition and project schedule affect role changes within the ecosystem. If the ecosystem already includes a sufficient variety of actors and the timeframe is sufficient, it is possible to plan in advance how to deal with possible challenges and the allocation of tasks and roles. If the timeframe is tight and the ecosystem is insufficient, certain challenges and the allocation of tasks and roles must be dealt with as they arise.
	- Potential new market niches (e.g., intermediate storage, refurbishment, second-hand sales of concrete elements) emerge for new actors	- In-house development for companies, particularly for the construction company - New concrete element "experts" needed for different phases of the reuse process	**New roles emerge:** The new tasks and requirements of concrete-element reuse call for new roles such as intermediate storage, refurbishment, and second-hand sale of concrete elements.
Interaction changes	- The close interaction among core actors led to open and inclusive communication within the industrial ecosystem and towards public authorities.	- Adoption of a positive and cooperative attitude within the project	**Communication changes:** Open communication and keeping all actors informed is important when developing innovation and new practices in an ecosystem. Objectives and needs must be openly communicated across the ecosystem.
	- Digital tools were utilized to support interorganizational communication.	- Mutual support and help for all tasks among the core actors	**Collaboration mindset:** Cooperative attitude, mutual support, and sharing expertise and know-how are crucial in solving unexpected challenges.
	- Expertise was shared openly during planning.	- Developing new and alternative design ideas for	**Utilization of tools:** Digital tools and technologies

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Table 2 (*continued*)

	Finland: Planned industrial ecosystem	Sweden: Evolving industrial ecosystem	Insights on changes and benefit types on different levels with examples
	Changes		
		the pilot building together	can enhance the efficiency of collaboration and improve information flow in the ecosystem.
Perception changes	- Shared understanding among core actors of the required innovative approach and the value of detached elements - New way of thinking for sub-planning (e.g., work safety and logistics) and redesign with detached elements - Reducing prejudices against utilizing new digital tools and technologies - Benchmarking ideas from other industries (e.g., how the paper industry dismantles equipment and reassembles it in a new location)	- Public-sector (particularly city of Helsingborg and the housing company) and company (concrete element manufacturer and construction company) environmental and sustainability goals led to a strong desire to develop sustainable solutions.	**Value of circulated resources:** If the ecosystem actors do not understand their role and the effect of their actions on others in the ecosystem, value can be destroyed for all parties. Thus, it is important to understand the value of the detached elements and handle them as valuable resources, not waste. **Design thinking:** Changing the way of thinking is necessary for architects when the starting point is predetermined detached elements instead of starting from scratch. **Change resistance to conformity:** Reducing change resistance towards reuse (e.g., regulators) and use of new methods and (digital) tools (companies).
Benefits from the changes			
Company benefits	- Role expansions and sharing expertise enable development of new skills and competences, supporting expansion to new business areas. - Digital tools and technologies improve information flow and open communication between companies. - Companies, particularly construction, demolition, architect, and designer, gain competitive advantage by being forerunners in sustainable transition. - More circular practices improve employee work satisfaction and engagement (e.g., reducing waste produced on demolition sites).	- Acquisition of competences and new skills opens new business opportunities. For example, the concrete element manufacturer gained an understanding of the whole reuse process and can thus identify whether there are any new lucrative business models (e.g., intermediate storage, refurbishment, second-hand sales). - Companies gain image benefits by operating according to CE and sustainable principles, which can be used in marketing and future competitions where CE and sustainable construction references are advantageous.	**Direct business benefits:** - Companies gain image benefits thanks to their circularity forerunner status. - New business opportunities arise from role expansions and new skills and competences. - Companies save by acquiring reused elements. The higher prices of new buildings reusing concrete elements may be acceptable to customers due to the circular approach. - Indirect market benefits include enhanced customer acquisition thanks to a circular construction approach. **Competence development benefits:** - Companies develop new skills and competences from the pilot project. - The competence portfolio and skill toolbox related to circularity is expanded and updated. - Ecosystem actors improve their problem-solving skills for circularity challenges. - Use of digital tools improves information flow and facilitates open communication between ecosystem actors. **Work satisfaction benefits:**

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Table 2 (*continued*)

	Finland: Planned industrial ecosystem	Sweden: Evolving industrial ecosystem	Insights on changes and benefit types on different levels with examples
	Changes		
			- Circular practices improve work satisfaction as employees can work in a sustainable way. This benefits the companies as workers are more engaged, boosting efficiency.
Industry benefits	- New practices (e.g., redesign), innovations (e.g., utilizing digital models), open communication, and sharing expertise in project meetings (particularly regarding deconstruction) boost competence development and collaboration in the industry. - Utilizing digital tools and technologies boosts the digitalization of the construction industry. - Close interaction with the city enhances collaboration with public actors. - Other companies will follow the forerunners to develop more resource-efficient practices.	- A new way of working develops collaboration between companies, stakeholders, and authorities through actors' joint problem-solving skills; open communication boosts the development of the whole construction industry. - As the companies recognize the value in detached elements, the construction industry moves towards resource-efficiency.	**Environmental benefits:** - Increased resource efficiency and material bank thinking. - More efficient use of materials and resources. - Increased environmental awareness and a shift towards more sustainable practices. **Competition benefits:** - Better competitive environment within the industry because when the forerunners adopt circular practices, others will follow. - Utilizing digital tools for circular construction supports the digitalization of the industry. - A new way of working provides a niche market for new business related to concrete-element reuse.

Table 2 (*continued*)

	Finland: Planned industrial ecosystem	Sweden: Evolving industrial ecosystem	Insights on changes and benefit types on different levels with examples
	Changes		
			- More circular practices improve the industry's image in terms of sustainability. **Industry feasibility benefits:** - New skills and competences developed for circular construction provide expertise for the industry, improving industry survival. - Circular construction provides new professions and thus new experts for the industry (e.g., deconstruction-/redesign-related).
Society benefits	- Reducing prejudices towards reuse of building components within society enhances reuse of materials on the societal level. - Recent media data and company reports indicate that society is slowly transitioning towards more circular practices through regulation updates (e.g., end-of-waste for recycled concrete aggregate) and innovation (e.g., reuse or 3D-printing of concrete). - Companies' innovation of new CE solutions challenging conventional practices boosts regulation updates.	- Utilizing reuse enables reduction of emissions and use of natural resources from the production of new precast concrete elements. - Reuse of concrete elements saves raw materials. If the construction industry does not innovate circular solutions, construction may slow down significantly or even stop temporarily due to the lack of raw materials. (For example, the raw materials needed for producing cement are running out in Sweden, according to media data and interviews).	**Environmental benefits:** - When environmentally burdensome industries (e.g., construction) take on more circular practices facilitated by societal change (e.g., updated regulation), society benefits by reduced environmental impacts (carbon footprint, energy consumption, reservation of virgin materials, and biodiversity). - New innovations in the construction industry provide tools for cities to transition towards more circular practices. **Employment benefits:** - New skills for workforce

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Table 2 (*continued*)

	Finland: Planned industrial ecosystem	Sweden: Evolving industrial ecosystem	Insights on changes and benefit types on different levels with examples
	Changes		
			- New jobs created when existing actors expand their activities or new actors emerge in the market, generating increased tax revenues

more environmentally sustainable practices and increased environmental awareness. Through these kinds of innovative pilot projects focusing on circularity, resource efficiency and material bank thinking gain ground in the construction industry, which shifts to more efficient use of material and resources, such as reuse and the prevention of waste generation. Innovative approaches lead to a better competitive environment as other construction companies follow the forerunners and compete through new circular innovations. By adopting digital technologies and tools in the reuse of concrete elements, companies can ensure a more efficient and safer working environment throughout the industry. The utilization of digital tools in the pilot projects also supports the digitalization of a traditional industry, paving the way for digitalization in other industries as well. More circular practices in the industry may also attract new talent into construction, although, given its conservative nature, its renewal process may be painfully slow.

Benefits for society stem from the reduced environmental impacts and creation of new skills and competences enabling the reuse of concrete elements. Concrete is among the largest sources of waste and greenhouse gas emissions globally. Reusing concrete components can use this waste and significantly reduce carbon footprint and energy consumption, compared to virgin production or aggregate recycling, in new construction, enabling the industry to save limited natural resources and contribute to the conservation of biodiversity. Implementing new practices in the construction industry enhances the skill development of the workforce and creates new jobs and tax revenues. Reusing concrete elements calls for new skills, potentially improving gender equality in the construction industry through providing less physically demanding new jobs and requiring more material analysis skills. However, wide-scale adoption of concrete-element reuse requires reduced resistance to change (e.g., among regulators) through proof that it is viable and safe.

The cases present two different paths of industrial ecosystem renewal providing similar benefits to individual companies, the construction industry, and society more broadly. The FPP involves a more extensive industrial ecosystem to support all the phases of concrete element reuse, whereas the SPP involves a smaller number of ecosystem actors sharing tasks and doing more in-house. Given their different schedules, the pilot project flows differ regarding, for example, the sourcing of concrete elements. Due to time constraints in Sweden, these elements were sourced wherever possible from multiple demolition sites; even factory rejects were utilized to complement the detached elements. This “lean sourcing” in Sweden is very different to the “planned sourcing” seen in Finland, where the deconstruction of one building was planned very thoroughly. The carefully detached elements during the well-prepared deconstruction in Finland were planned for use in multiple new buildings with a high utilization rate, which required more careful planning and preparation than the temporary pilot building built for the housing fair in Sweden. Due to the tight planning, design, and construction schedule in the SPP, challenges were solved in a lean way when they were encountered, whereas in Finland the ecosystem aimed to plan ahead, decreasing the difficulties faced during deconstruction and construction.

Both pilot projects presented a variety of interesting changes in the industrial ecosystems regarding roles, interactions, and perceptions. The changes in *roles* of the industrial ecosystem actors included major role expansions for most companies involved. In Finland, the companies participated in planning tasks by sharing expertise and creating new ways of working. As fewer actors were involved in the SPP, they expanded their conventional roles significantly and, due to the tight schedule, took on new responsibilities as the project progressed. In the future, new roles may emerge to deal with the new tasks, and some roles, such as demolition waste management, may be reduced. The *interaction* within the industrial ecosystems changed towards a more open and collaborative communication style than in conventional construction projects. Collaboration, co-development, and open communication were central to the success of both projects. It emerged from the discussed role changes in both ecosystems that the contribution of different actors is needed in multiple project phases. In conventional construction projects, each subcontractor only carries out their own tasks. In contrast, for concrete-element reuse projects, close communication and sharing expertise and support in different tasks are key due to the adoption of new tools and practices. Regarding *perception* changes, it is vital that everyone understands the value of the detached elements so no one destroys the value potential of another actor. This understanding will also help society find alternative sustainable and circular solutions for the discarded goods of one actor. Reducing waste and the use of virgin raw materials results in better preservation of biodiversity, and industrial actors can use recycled or reused materials instead of virgin ones for new products. During the co-development within the project, the ecosystem had to embrace innovative approaches and adopt new ways of working and planning regarding, for example, the sub-plans for safe and smooth deconstruction and redesign with the predefined detached elements.

Some of the changes in the ecosystems for concrete element reuse in our study were more temporary, due to the task division of the pilot projects, while some changes may lead to, for example, more permanent role expansions for companies through new capabilities. Even through concrete-element reuse differs significantly from conventional construction, according to our observations the ecosystem actors mostly seemed to want to stick to their conventional roles. However, some of their tasks needed to be done differently when aiming for reuse, thus expanding their roles through new capabilities and expertise. For example, the architect had to work with predetermined elements instead of starting from scratch, and the engineering company had a more extensive role throughout the reuse project. We have identified that the second-hand market for concrete elements provides a new business model opportunity as a new actor would be needed to take care of refurbishing, intermediate storage, and selling the elements if the incumbent companies (e.g., concrete element manufacturer) don’t want to expand their business models more permanently after piloting. In addition, in FPP and SPP the universities coordinated the pilot projects and collaboration within the ecosystem. Therefore, in future “business-as-usual” projects, the main contractor may need to take the coordinator role to enable concrete-element reuse.

To conclude, industry ecosystem renewal towards circularity requires changes in roles, interactions, and perceptions to enable benefits across micro, meso, and macro levels (see Fig. 4). Companies gain competence development, work satisfaction, and direct business benefits. The construction industry gains environmental, competition, and industry feasibility benefits, and more circular practices decrease its environmentally burdensome image, making it more attractive to new talent. The construction industry may gain new companies as learnings from the new concept open up market niches. Society gains environmental and employment benefits as concrete-element reuse reduces environmental impacts and provides new skills and new jobs for the workforce. Furthermore, the public sector may benefit from companies’ circular solutions in urban areas, which guides cities towards more

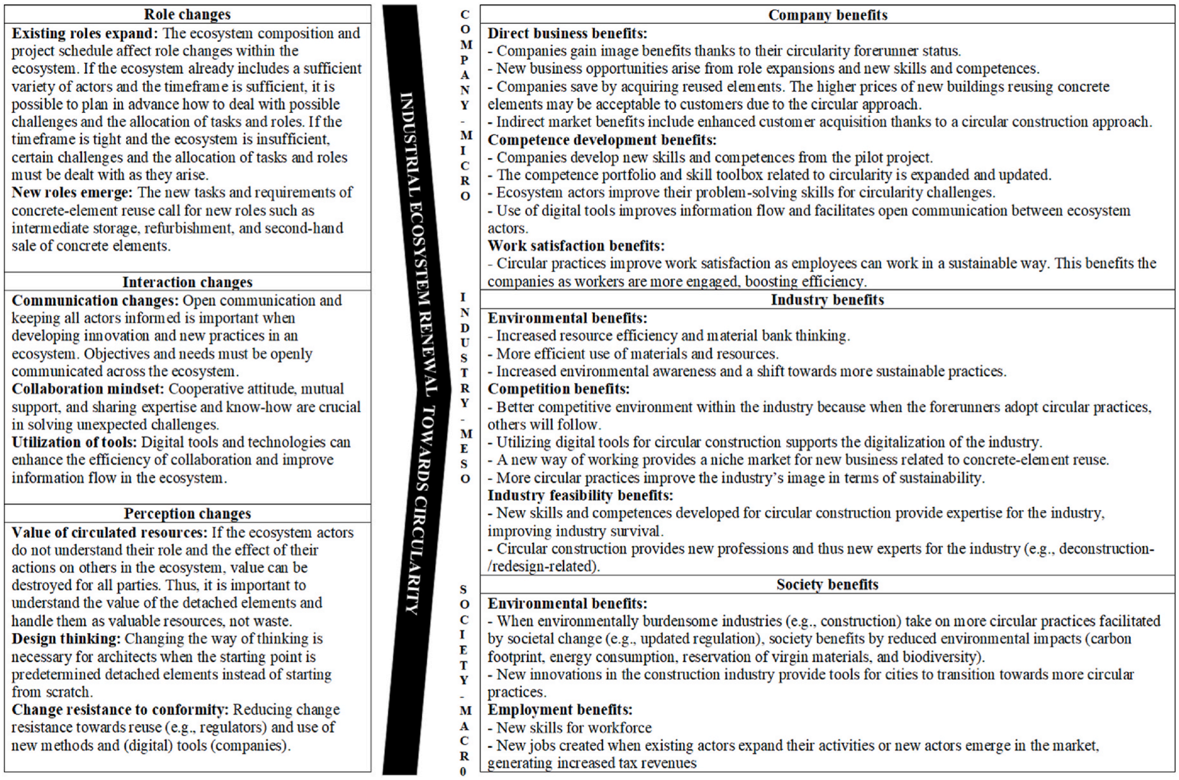

Fig. 4. The required changes to gain benefits from CE.

circular practices.

Even though we focused on the circular industrial ecosystem characteristics of the cases, we identified that when taking company-centric business ecosystem lenses, the cases actually entailed individual companies' business ecosystems and their renewed circular value propositions, due to increased circularity and reuse. For example, for the concrete element manufacturer to take over the second-hand market of concrete elements (providing e.g., refurbishment, intermediate storage, and sales of the deconstructed elements) requires that its business ecosystem embedded in the focal industrial ecosystem provides deconstructed elements, e.g., via smart deconstruction. A demolition company can provide this new deconstruction service, and hence its business model and its business ecosystem change. While the cases presented how the ecosystem actors innovated together, the cases reflect also characteristics of innovation ecosystems. Thus, CE ecosystems serve as an appropriate overarching concept (Aarikka-Stenroos et al., 2021) for the studied ecosystems; however, our cases indicate that circular industrial, innovation, and business ecosystems can co-exist.

6. Conclusions

6.1. Theoretical contribution

Our study analyzing how two industry ecosystems from construction sector renew towards circularity via increased reuse contributes to research on CE ecosystems, circular construction, CE research, and research on industry-level CE-transformation.

Firstly, regarding research on CE ecosystems we provide insights on two industrial ecosystems renewing their practices to enable concrete-element reuse, thus contributing to ecosystem research (Aarikka-Stenroos et al., 2021) by mapping the industrial ecosystem actors and examining their roles, interactions, and perceptions during industrial ecosystem renewal.

Secondly, our findings contribute to circular construction research (Buyle et al., 2019; Malmqvist et al., 2020) by showing how different actors need to collaborate to promote circularity in the construction industry. Although our research focuses on the construction industry, our results contribute to other environmentally burdensome industries aiming to transform towards circularity.

Thirdly, we contribute to CE research focusing on reuse instead of the more thoroughly studied recycling (Ghisellini et al., 2016; Ranta et al., 2018a,b; Norouzi et al., 2021) by analyzing the prerequisites of concrete-element reuse, in particular which actors are needed to work together to enable reuse.

Fourthly, our study uncovers how industry-level CE transformation and changes generate benefits on the company, industry, and societal levels. Thus, our study extends previous literature on industry-level CE initiatives as it has mainly examined individual material flows (Lieder and Rashid, 2016; Fisher & Pascucci, 2017; Ghisellini et al., 2018; Moktadir et al., 2018; Joensuu et al., 2020). In addition, we create understanding of the changes required when industries aim to transition to CE (Anastasiades et al., 2020; Ghisellini et al., 2016; Hagbert and Malmqvist, 2019). We contribute by explaining how the circular transition of an industry creates not only benefits on the meso level, for the industry, but also macro- and micro-level benefits (Ghisellini et al., 2018; Hossain et al., 2018; Nußholz et al., 2020; Ranta et al., 2018a,b).

6.2. Practical implications

For companies, and their technology- and business-oriented managers, this study guides collaboration, and role and task division, within industrial ecosystems. We provide insights on the changes needed in ecosystems' roles, interactions, and perceptions and the benefits individual companies gain from concrete-element reuse, as well as knowledge and guidance for development, business, and sustainability managers to improve transitions towards more sustainable practices.

For the construction industry, we give an overview of industrial ecosystem renewal and concrete-element reuse to enable assessment of scalability potential and competence needs. Therefore, our study provides insights into the issues raised by industry renewal, such as changes within the industry and the benefits they yield. Furthermore, our study provides valuable information to industry associations on how the construction industry can evolve towards more circular and sustainable practices and, on a larger scale, guides industry development initiatives that often require collaboration between multiple actors.

More broadly, our study gives tools for societal-level actors such as policymakers by providing information and knowledge of the new way of working and its benefits. Hence, our findings also elucidate the different roles of supporting actors (e.g., authorities and cities) in the reuse ecosystem and provide information for future decision-making.

6.3. Limitations and future research

As this study focuses on a single industry, namely the construction industry, future research should examine different industries to obtain a more comprehensive overview of what reuse requires. Moreover, we chose projects from Nordic countries (Finland and Sweden) which have similar policies and cultures. In these two relatively small countries, implementing country-level circular approaches may be easier and more feasible than in larger ones where companies' business operations may be spread widely across the country. Hence, future research may also be expanded geographically to larger countries and different institutional contexts.

Since our multiple-case study stems from an EU project, with most of the ecosystem actors already being engaged in the pilot projects, studying reuse in cases where actors are less engaged could provide new perspectives on the challenges, opportunities, facilitation, and adoption of reuse principles in the industrial setting. Such a study could provide firms and industries with insights on how to improve the development and adoption of reuse in an ecosystem setting in a way that encourages the adoption of CE principles and industries' transition towards more sustainable practices.

CRediT authorship contribution statement

Linnea Harala: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Project administration, Visualization. **Lauri Alkki:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Leena Aarikka-Stenroos:** Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Ahmad Al-Najjar:** Conceptualization, Validation, Formal analysis, Investigation, Writing – original draft. **Tove Malmqvist:** Conceptualization, Validation, Formal analysis, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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References

Aarikka-Stenroos, L., Ritala, P., 2017. Network management in the era of ecosystems: systematic review and management framework. Ind. Market. Manag. 67, 23–36. https://doi.org/10.1016/j.indmarman.2017.08.010.

Aarikka-Stenroos, L., Ritala, P., Thomas, L.D.W., 2021. Circular economy ecosystems: a typology, definitions, and implications. In: Teerikangas, S., Onkila, T., Koistinen, K., Mäkela, M. (Eds.), Research Handbook of Sustainability Agency. Edward Elgar Publishing, pp. 257–273.

February Adams, K.T., Osmani, M., Thorpe, T., Thornback, J., 2017. Circular economy in construction: current awareness, challenges and enablers, 1. In: Proceedings of the Institution of Civil Engineers-Waste and Resource Management, vol. 170. Thomas Telford Ltd, pp. 15–24. https://doi.org/10.1680/jwarm.16.00011.

Adner, R., 2017. Ecosystem as structure. J. Manag. 43 (1), 39–58. https://doi: 10.1177/0149206316678451.

Ajayi, S.O., Oyedele, L.O., Bilal, M., Akinade, O.O., Alaka, H.A., Owolabi, H.A., Kadiri, K. O., 2015. Waste effectiveness of the construction industry: understanding the impediments and requisites for improvements. Resour. Conserv. Recycl. 102, 101–112. https://doi.org/10.1016/j.resconrec.2015.06.001.

Anastasiades, K., Blom, J., Buyle, M., Audenaert, A., 2020. Translating the circular economy to bridge construction: lessons learnt from a critical literature review. Renew. Sustain. Energy Rev. 117 https://doi.org/10.1016/j.rser.2019.109522.

Ayres, R.U., Ayres, L.W., 2002. A Handbook of Industrial Ecology. Edward Elgar Publishing.

Buyle, M., Galle, W., Debacker, W., Audenaert, A., 2019. Sustainability assessment of circular building alternatives: consequential LCA and LCC for internal wall assemblies as a case study in a Belgian context. J. Clean. Prod. 218 (1), 141–156. https://doi.org/10.1016/j.jclepro.2019.01.306.

Cheng, E.W., Li, H., Love, P.E., Irani, Z., 2001. Network communication in the construction industry. Corp. Commun. Int. J. 6 (2), 61–70. https://doi.org/10.1108/13563280110390314.

Chileshe, N., Rameezdeen, R., Hosseini, M.R., Martek, I., Li, H.X., Panjehbashi-Aghdam, P., 2018. Factors driving the implementation of reverse logistics: a quantified model for the construction industry. Waste Manag. 79, 48–57. https://doi.org/10.1016/j.wasman.2018.07.013.

De Angelis, R., Howard, M., Miemczyk, J., 2018. Supply chain management and the circular economy: towards the circular supply chain. Prod. Plann. Control 29 (6), 425–437. https://doi.org/10.1080/09537287.2018.1449244.

De Wolf, C., Hoxha, E., Fivet, C., 2020. Comparison of environmental assessment methods when reusing building components: a case study. Sustain. Cities Soc. 61, 102322 https://doi.org/10.1016/j.scs.2020.102322.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14 (4), 532–550.

Engez, A., Ranta, V., Aarikka-Stenroos, L., 2021. How innovations catalyze the circular economy: building a map of circular economy innovation types from a multiple-case study. In: Jakobsen, S., Lauvås, T., Rasmussen, Q. Quatraro E., Steinmo, M. (Eds.), Research Handbook of Innovation for a Circular Economy. Edward Elgar.

Farooque, M., Zhang, A., Thürer, M., Qu, T., Huisingh, D., 2019. Circular supply chain management: a definition and structured literature review. J. Clean. Prod. 228, 882–900. https://doi.org/10.1016/j.jclepro.2019.04.303.

Fischer, A., Pascucci, S., 2017. Institutional incentives in circular economy transition: the case of material use in the Dutch textile industry. J. Clean. Prod. 155, 17–32. https://doi.org/10.1016/j.jclepro.2016.12.038.

Flick, U., 2004. Triangulation in qualitative research. In: Flick, U., von Kardorff, E., Steinke, I. (Eds.), A Companion to Qualitative Research, third ed. SAGE, London, pp. 178–183.

Frosch, R.A., Gallopoulos, N.E., 1989. Strategies for manufacturing. Sci. Am. 261 (3), 144–153.

Geissdoerfer, M., Savaget, P., Bocken, N.M., Hultink, E.J., 2017. The circular economy–A new sustainability paradigm? J. Clean. Prod. 143, 757–768. https://doi: 10.1016/j.jclepro.2016.12.048.

Geng, Y., Côté, R., 2007. Diversity in industrial ecosystems. Int. J. Sustain. Dev. World Ecol. 14 (4), 329–335. https://doi.org/10.1080/13504500709469733.

Geueke, B., Groh, K., Muncke, J., 2018. Food packaging in the circular economy: overview of chemical safety aspects for commonly used materials. J. Clean. Prod. 193, 491–505. https://doi.org/10.1016/j.jclepro.2018.05.005.

Ghaffar, S.H., Burman, M., Braimah, N., 2020. Pathways to circular construction: an integrated management of construction and demolition waste for resource recovery. J. Clean. Prod. 244 https://doi.org/10.1016/j.jclepro.2019.118710.

Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32. https://doi: 10.1016/j.jclepro.2015.09.007.

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

Guerra, B.C., Leite, F., 2021. Circular economy in the construction industry: an overview of United States stakeholders' awareness, major challenges, and enablers. Resour. Conserv. Recycl. 170, 105617 https://doi.org/10.1016/j.resconrec.2021.105617.

Haas, W., Krausmann, F., Wiedenhofer, D., Heinz, M., 2015. How circular is the global economy?: an assessment of material flows, waste production, and recycling in the European Union and the world in 2005. J. Ind. Ecol. 19 (5), 765–777. https://doi.org/10.1111/jiec.12244.

Hagbert, P., Malmqvist, T., 2019. Actors in transition: shifting roles in Swedish sustainable housing development. J. Hous. Built Environ. 34 (3), 697–714. https://doi.org/10.1007/s10901-019-09695-7.

Hansen, E.G., Revellio, F., 2020. Circular value creation architectures: make, ally, buy, or laissez-faire. J. Ind. Ecol. 24 (6), 1250–1273. https://doi.org/10.1111/jiec.13016.
Hopkinson, P., Chen, H.M., Zhou, K., Wang, Y., Lam, D., 2019. Recovery and reuse of structural products from end-of-life buildings. Proc. Instit. Civil Eng. Eng. Sustain. 172 (3), 119–128. https://doi.org/10.1680/jensu.18.00007.
Hossain, M.U., Ng, S.T., 2018. Critical consideration of buildings' environmental impact assessment towards adoption of circular economy: an analytical review. J. Clean. Prod. 205, 763–780. https://doi.org/10.1016/j.jclepro.2018.09.120.
Hossain, M.U., Ng, S.T., Antwi-Afari, P., Amor, B., 2020. Circular economy and the construction industry: existing trends, challenges and prospective framework for sustainable construction. Renew. Sustain. Energy Rev. 130 https://doi.org/10.1016/j.rser.2020.109948.
Huang, B., Wang, X., Kua, H., Geng, Y., Bleischwitz, R., Ren, J., 2018. Construction and demolition waste management in China through the 3R principle. Resour. Conserv. Recycl. 129, 36–44. https://doi.org/10.1016/j.resconrec.2017.09.029.
Ingstrup, M.B., Aarikka-Stenroos, L., Adlin, N., 2020. When institutional logics meet: alignment and misalignment in collaboration between academia and practitioners. Ind. Market. Manag. 92, 267–276. https://doi: 10.1016/j.indmarman.2020.01.004.
Inigo, E.A., Blok, V., 2019. Strengthening the socio-ethical foundations of the circular economy: lessons from responsible research and innovation. J. Clean. Prod. 233, 280–291.
Iuorio, O., Napolano, L., Fiorino, L., Landolfo, R., 2019. The environmental impacts of an innovative modular lightweight steel system: the Elissa case. J. Clean. Prod. 238, 117905 https://doi.org/10.1016/j.jclepro.2019.117905.
Joensuu, T., Edelman, H., Saari, A., 2020. Circular economy practices in the built environment. J. Clean. Prod. 276, 124215 https://doi.org/10.1016/j.jclepro.2020.124215.
Kaipainen, J., Aarikka-Stenroos, L., 2022. How to Renew Business Strategy to Achieve Sustainability and Circularity? A Process Model of Strategic Development in Incumbent Technology Companies. Business Strategy and the Environment.
Kibert, C.J., Chini, A., Languell, J.L., Rinker, M.E., 2000. Implementing Deconstruction in the United States. Overview of Deconstruction in Selected Countries, pp. 181–239.
Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: an analysis of 114 definitions. Resour. Conserv. Recycl. 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005.
Korhonen, J., 2001. Four ecosystem principles for an industrial ecosystem. J. Clean. Prod. 9 (3), 253–259. https://doi.org/10.1016/S0959-6526(00)00058-5.
Korhonen, J., 2007. Environmental planning vs. systems analysis: four prescriptive principles vs. four descriptive indicators. J. Environ. Manag. 82 (1), 51–59. https://doi.org/10.1016/j.jenvman.2005.12.003.
Korhonen, J., Snäkin, J.P., 2005. Analysing the evolution of industrial ecosystems: concepts and application. Ecol. Econ. 52 (2), 169–186. https://doi.org/10.1016/j.ecolecon.2004.07.016.
Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in the context of manufacturing industry. J. Clean. Prod. 115, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042.
Lowe, E.A., Evans, L.K., 1995. Industrial ecology and industrial ecosystems. J. Clean. Prod. 3 (1–2), 47–53. https://doi.org/10.1016/0959-6526(95)00045-G.
Malmqvist, T., Moncaster, A., Rasmussen, F., Birgisdóttir, H., 2020. Circularity in the built environment: a call for a paradigm shift. In: Brandao, M., Lazarevic, D., Finnveden, G. (Eds.), Handbook of the Circular Economy. Edward Elgar Publishing, pp. 425–438.
Mayring, P., 2004. Qualitative content analysis, 2. In: A Companion to Qualitative Research, vol. 1. SAGE Publications, pp. 159–176.
Milios, L., Beqiri, B., Whalen, K.A., Jelonek, S.H., 2019. Sailing towards a circular economy: conditions for increased reuse and remanufacturing in the Scandinavian maritime sector. J. Clean. Prod. 225, 227–235. https://doi.org/10.1016/j.jclepro.2019.03.330.
Moktadir, M.A., Rahman, T., Rahman, M.H., Ali, S.M., Paul, S.K., 2018. Drivers to sustainable manufacturing practices and circular economy: a perspective of leather industries in Bangladesh. J. Clean. Prod. 174, 1366–1380. https://doi.org/10.1016/j.jclepro.2017.11.063.
Norouzi, M., Chàfer, M., Cabeza, L.F., Jiménez, L., Boer, D., 2021. Circular economy in the building and construction sector: a scientific evolution analysis. J. Build. Eng. 44, 102704 https://doi.org/10.1016/j.jobe.2021.102704.
Nußholz, J.L., Rasmussen, F.N., Whalen, K., Plepys, A., 2020. Material reuse in buildings: implications of a circular business model for sustainable value creation. J. Clean. Prod. 245 https://doi.org/10.1016/j.jclepro.2019.118546.
Pomponi, F., Moncaster, A., 2017. Circular economy for the built environment: a research framework. J. Clean. Prod. 143 (1), 710–718. https://doi.org/10.1016/j.jclepro.2016.12.055.
Rakhshan, K., Morel, J.C., Alaka, H., Charef, R., 2020. Components reuse in the building sector–A systematic review. Waste Manag. Res. 38 (4), 347–370. https://doi.org/10.1177/0734242X20910463.
Ranta, V., Aarikka-Stenroos, L., Ritala, P., Mäkinen, S.J., 2018a. Exploring institutional drivers and barriers of the circular economy: a cross-regional comparison of China, the US, and Europe. Resour. Conserv. Recycl. 135, 70–82. https://doi: 10.1016/j.resconrec.2017.08.017.
Ranta, V., Aarikka-Stenroos, L., Mäkinen, S.J., 2018b. Creating value in the circular economy: a structured multiple-case analysis of business models. J. Clean. Prod. 201, 988–1000.
Reike, D., Vermeulen, W.J.V., Witjes, S., 2018. 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. Resour. Conserv. Recycl. 135, 246–264. https://doi: 10.1016/j.resconrec.2017.08.027.
Robson, C., 2002. Real World Research: A Resource for Social Scientists and Practitioner-Researchers. Blackwell Publishing.
Russell, J., Nasr, N., 2019. Value-retention processes within the circular economy. In: Nasr, N. (Ed.), Remanufacturing in the Circular Economy: Operations, Engineering and Logistics. Wiley, pp. 1–29. https://doi: 10.1002/9781119664383.ch1.
Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., Kendall, A., 2019. A taxonomy of circular economy indicators. J. Clean. Prod. 207, 542–559. https://doi.org/10.1016/j.jclepro.2018.10.014.
Smol, M., Kulczycka, J., Henclik, A., Gorazda, K., Wzorek, Z., 2015. The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy. J. Clean. Prod. 95, 45–54. https://doi.org/10.1016/j.jclepro.2015.02.051.
Stahel, W.R., 2016. The circular economy. Nature 531, 435–438. https://doi.org/10.1038/531435a.
Thomas, L.D.W., Autio, E., 2020. Innovation Ecosystems in Management: an Organizing Typology. https://doi: 10.1093/ACREFORE/9780190224851.013.203.
Tsvetkova, A., Gustafsson, M., 2012. Business models for industrial ecosystems: a modular approach. J. Clean. Prod. 29, 246–254. https://doi.org/10.1016/j.jclepro.2012.01.017.
Union, European, 2022. Definition of industrial ecosystems. Eur. Cluster Collab. Platform. Available online: https://clustercollaboration.eu/in-focus/industrial-ecosystems/definition.
Urbinati, A., Chiaroni, D., Chiesa, V., 2017. Towards a new taxonomy of circular economy business models. J. Clean. Prod. 168, 487–498. https://doi.org/10.1016/j.jclepro.2017.09.047.
Valkokari, K., 2015. Business, innovation, and knowledge ecosystems: how they differ and how to survive and thrive within them. Technol. Innov. Manag. Rev. 5 (8) https://doi.org/10.22215/timreview/919.
van Langen, S.K., Vassillo, C., Ghisellini, P., Restaino, D., Passaro, R., Ulgiati, S., 2021. Promoting circular economy transition: a study about perceptions and awareness by different stakeholders groups. J. Clean. Prod. 316, 128166.
Wijewickrama, M.K.C.S., Rameezdeen, R., Chileshe, N., 2021. Information brokerage for circular economy in the construction industry: a systematic literature review. J. Clean. Prod. 313, 127938 https://doi.org/10.1016/j.jclepro.2021.127938.
Yin, R.K., 2009. Case Study Research, Design & Methods, fourth ed. SAGE.
Zabek, M., Hildebrand, L., Brell-Cokcan, S., Wirth, M., 2017. Used building materials as secondary resources – identification of valuable building material and automized deconstruction. J. Facade Des. Eng. 5 (2), 25–33. https://doi.org/10.7480/jfde.2017.2.1684.