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Toward a collaborative circular ecosystem within the built environment

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ABSTRACT

The built environment has drastically transitioned toward the circular economy (CE) to reduce carbon footprint, waste emission, and resource consumption. The circular ecosystem with close collaboration between diverse actors is critical to the sector's CE transition success. However, a holistic perspective on the circular ecosystem of the built environment remains lacking. This paper provides new insights into the complex and intricate dynamics of actor collaborations in the circular building ecosystems on the niche and regime levels. Moreover, this study shows the orchestrating roles of the municipalities and developers as the 'keystone' actors in the circular ecosystem. It also stresses the increasingly significant roles of new actors as the driving forces for the socio-technical paradigm shift toward CE in construction. The actor collaboration in the circular building ecosystem has been shifted to more collaborative and multi-dimensional (i.e., top-down, bottom-up, and horizontal). We also map the actor networks using CE principles and explain the importance of addressing incentives for stronger actor collaborations. Finally, this paper provides policy and managerial implications to reinforce collaboration dynamics and CE practices in the built environment.

1. Introduction

The built environment has led to severe environmental issues of greenhouse gas (GHG) emissions, waste generation, raw material and energy overconsumption, and landfill overuse. The pervasive dominance of the conventional linear system of the building sector is believed to be the leading cause of these problems. (Pomponi and Moncaster, 2017). Construction and demolition activities consume 34 % of global energy demand and approximately 40 % of global raw materials, including 40 % of steel and 50 % of concrete and brick (European Commission, 2020a). The overextraction of virgin materials has depleted natural resources and generated GHG. The built environment releases about 5–12 % of total national GHG emissions during material extraction, material production, construction, and renovation processes (European Commission, 2020). In Europe, construction and demolition generate about two million tons of annual waste, including various materials such as concrete, bricks, wood, glass, metals, and plastics. In contrast, up to 46 % of end-of-life materials can still be reusable or recyclable but are deposited into landfills.

Global actions have been taken to address the construction sector's problem. The European Commission (2020) has emphasised the importance of the circular economy (CE) transition of decarbonising through energy efficiency and material reuse within the built environment The goals are set to reduce GHG emissions of buildings by 60 % and energy consumption by 14 % by 2030 given that "applying circularity principles to building renovation will reduce material-related GHG emissions for buildings." (European Commission, 2020, p. 2). Material efficiency might also reduce up to 80 % of those emissions (European Commission, 2020).

The CE is seen as an integrated, multi-level, multi-peripheral and multi-actor approach involving diverse groups of actors and complex circular ecosystems (Konietzko et al., 2020). The CE transition of the construction sector involves multi-actor collaborations throughout the whole building lifecycle from design, construction and operation to material reuse and waste management. New actors would create significant socio-technical changes in a circular building ecosystem. Dynamic and effective multi-actor collaborations are prerequisites to ensure the embeddedness of CE principles at every stage of a building's lifetime.

However, actor collaboration in the circular construction sector has faced unique challenges due to a long traditional linear mindset among the sectoral actors. Addressing these challenges and promoting a more collaborative circular ecosystem within this sector requires a better understanding of the complex relationships of the actors, the interplay of the actors, and the influential factors.

Regardless, knowledge about the circular ecosystem within the built environment is significantly limited despite the need for a circular ecosystem perspective being raised by previous studies (Konietzko et al.,

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2020; Gomes et al., 2023; Thakur and Wilson, 2023). Most research is focused on the particular stages (e.g., waste management or design), specific stakeholders, or digital technologies (e.g., blockchain). It lacks a holistic approach to achieving a comprehensive understanding of the whole value system and network (Rakhshan et al., 2020). The current literature does not thoroughly examine how different actors in the built environment are interdependent through a complex circular ecosystem of intertwined new technologies, knowledge, and data.

Furthermore, actor collaboration is hindered by multiple barriers concerning technical, economic, and cultural aspects. However, most research on the circular built environment places too much emphasis on the technical side but too little on the value chain and market-driven aspects where the CE incentives among the actors are affected. For instance, Tingley et al. (2017) and Martin et al. (2024) highlighted that barriers to developing circular buildings relate to technical obstacles and systematic factors entangled with market gaps and regulation issues. Joensuu et al. (2020) and Munaro et al. (2020) have also called for further research on the value chain of the circular built environment.

Dokter et al. (2021, p. 695) highlighted that "the transition to a CE will not succeed if companies attempt to overcome barriers individually; rather, they will need to establish new ways of working, new business partners, new roles for existing partners, and new kinds of collaborations between stakeholders". Understanding and establishing a collaborative circular ecosystem is critical for the CE success of this sector (Ghisellini et al., 2018). Thus, this study's research question is: "*How do the existing and new actors collaborate in an integrated circular ecosystem of the built environment*?"

This study aims to contribute to the literature on the CE, innovation studies, and the built environment by offering a novel, systematic view of the entire circular building ecosystem and providing insights into fostering actor collaboration dynamics. In addition, the paper also elaborates on the roles of new actors as catalysts for socio-technical-market changes in the ecosystem. Finally, the study suggests nuanced policies to reinforce the CE transition of the built environment.

2. Literature review

2.1. Circular economy in the built environment

CE is a contemporary but increasingly significant concept, with a focus on a closed-loop economy generated by decoupling resource consumption, extending product lifecycles, and minimising waste and GHG emissions (Kirchherr et al., 2017). The EU's Circular Economy Action Plan (2020, p.11) underscores "ensure coherence across the relevant policy areas, such as climate, energy and resource efficiency, management of construction and demolition waste, accessibility, digitalisation and skills" for the building sector.

Compared to the concept of sustainability introduced before the CE, both CE and sustainability aim to improve environmental performance. However, what distinguishes the CE concept is its focus on specific circular strategies, often known as the 'R' strategies (see Table 1), to achieve particular goals (Geissdoerfer et al., 2017). One reason for the increased feasibility and adoption of the CE in practice is tangible economic benefits, such as boosted profits, job opportunities, and economic growth (Lieder and Rashid, 2016). Not all firms are circular-born or initially incentivised by environmental concerns (Huynh and Rasmussen, 2021), and economic incentives often serve as primary intentions for CE adoption. Minimising positive environmental and social outcomes would be achieved through these economic incentives, including reducing waste, minimising resource extraction, and improving social well-being (Lieder and Rashid, 2016).

The CE of the building sector involves designing for reusing and extending utility longer, optimising and prolonging building lifecycle performances, selecting and using more sustainable materials, recovering and reusing secondary materials, using energy efficiently, and taking advantage of disruptive technologies. (Joensuu et al., 2020).The

Table 1
the 10R circular strategies in the built environment.

Circular strategies	Applications in the built environment
1. Reduce	Reduce energy and resource consumption in operation (electricity, water, heating). Reduce construction waste.
2. Reuse	Reuse materials and products from demolished buildings.
3. Recycle	Recycle materials and products from demolished buildings.
4. Regenerate	Convert or regenerate waste to inputs for other sectors.
5. Rethink	Rethink "CE principles" in building design and planning.
6. Refuse	Refuse non-sustainable materials.
7. Repair	Maintenance and rehabilitation of existing buildings to last longer.
8. Repurpose	Repurpose buildings for reuse.
9. Recover	Recover existing buildings or reclaimed materials.
10. Replace	Replace unsustainable materials with bio/ more sustainable/ renewable materials.

Source: Adapted from Nussholz et al. (2024)*,* van Stijn and Gruis (2019)*,* Çimen (2021) ***and*** Elsacker et al. (2020)*.*

CE has taken the central stage in the policies of the built environment. Still, the sector's transition process has stagnated and needs more substantial effort. More significant emphasis on adopting circular business model innovations and implementing closed-loop, circular strategies for building projects has been placed in the Norwegian CE Action Plan (2024) and European CE action plans (2020b). Circular strategies are applicable and adaptable across the entire lifecycle of buildings (i.e. construction, renovation, and demolition) and can be integrated into new business models (Nußholz et al., 2023). CE in construction is referred to as "the design and construction as well as the use phase, the smart operation, and maintenance of the built environment. A circular economy in construction is also a solution towards the environmental impacts of buildings." (Walter, 2024, p. xvii).

CE includes three main principles narrowing (i.e., using fewer material inputs and improving efficiency), slowing (i.e., maintaining product and material lifecycle longer in the loop), and closing (i.e., recycling and regenerating waste) the resource loop (Bocken et al., 2016). The CE of the built environment is strongly connected to these three CE principles of narrowing, slowing, and closing the loop (Chen et al., 2022).

First, 'narrowing the loop' involves improving building operations and opting for materials with higher decarbonisation benefits (Chen et al., 2022; Nußholz et al., 2023). For example, sewage sludge ash waste can be an alternative material for producing various building materials, such as bricks and tiles, aggregates for concrete and mortar, or even subbases and embankments in road infrastructure (Górecki et al., 2019). These material alternatives significantly reduce waste and GHG emissions within and across construction sectors. Moreover, the 'narrowing the loop' principle entails energy efficiency and resource optimisation during the building operation stage (Nussholz et al., 2024). Another notable effort is the work on Zero Emissions Buildings (ZEB), which have significantly low energy needs and high energy performance and are supplied by renewable energy sources. A ZEB produces enough renewable energy to compensate for the building's GHG emissions over its lifespan.

Second, 'slowing the loop' focuses on extending the building's lifetime by repair, maintenance, or repurposing to keep buildings longer in the loop. For example, an old office building can be repurposed for another use, such as social housing or a cultural centre, rather than being demolished or newly built (Gursel et al., 2023). Repurposing would reduce the impact of GHG up to 20–41 % compared to new construction (Assefa and Ambler, 2017).

Third, 'closing the loop' primarily involves recycling and reusing materials at the end of a building life (Chen et al., 2022; Nußholz et al., 2023). Material reuse has been considered a key strategy to close the material loop within the built environment (Nußholz et al., 2020). A number of reclaimed materials and components can be directly reused without transforming and recycling. Other reclaimed materials can be recycled through an industrial symbiosis within a value chain or between the different value chains (Norouzi et al., 2021). For instance, materials like cement or asphalt from buildings could be reused and recycled as material inputs for other sectors, such as road and infrastructure construction. Similarly, reusable polystyrene from plastic insulation in buildings may be grounded, recycled, and reused by different industries. An important aim is to reuse the materials without adding more energy for transformation.

To achieve the three principles, '3R' or extended '9R' circular strategies are often adopted(Morseletto, 2020). Table 1 summarises the 10R strategies in the circular built environment. In the context of the built environment, Çimen (2021) introduced the 'Replace' related to selecting polluting materials like concrete or steel with more circular and renewable materials, such as wood, which emit lower levels of GHG. Similarly, biomaterials such as mycelium-based composites can be floor tile alternatives (Elsacker et al., 2020).

The priorities of the CE strategies and principles depend on the intrinsic characteristics of each sector, which has distinctive products and groups of actors. In construction, closing the loop through material reuse and recycling and slowing the loop through building renovation, maintenance, and repair are highlighted in practice, research and policies, such as those of Interreg Europe and the European Commission.[1] CE activities such as maintenance and direct material reuse without further energy and resource consumption for processing, transforming, and recycling should be prioritised.

2.2. A collaborative circular ecosystem of the built environment

One crucial determinant for the CE transition is the circular ecosystem where heterogeneous actors are interdependent and linked through a mutual value proposition (Aarikka-Stenroos et al., 2021). Trevisan et al. (2022, p. 292) define the circular innovation ecosystem as "a system of interdependent and heterogeneous actors that go beyond industrial boundaries and direct the collective efforts toward a circular value proposition, providing opportunities for economic and environmental sustainability". Compared to other ecosystems, the circular ecosystem is distinguished as a system "oriented to materialise a circular ecosystem value proposition based on CE principles" (Gomes et al., 2023, p. 2).

The actor interdependencies are attributed to physical interconnection, spatial proximity, technological complementarities, economic incentives, and cognition that would shape the actors' roles in the ecosystem (Aarikka-Stenroos et al., 2021). Actors hold unique roles and resources to influence system changes and to co-create circular value propositions. Among a group of heterogeneous actors, "keystones" or "orchestrators" act as the central actors to facilitate the ecosystem.

Aarikka-Stenroos et al. (2021, p. 268) have defined the circular ecosystem of the built environment as the 'industrial and urban ecosystems' referring to "a regional community of hierarchically independent, yet interdependent heterogeneous set of actors who sustainably produce industrial goods and services in symbolic collaboration and resource use". Given this context, buildings and infrastructures are considered 'industrial goods' of the built environment. A circular building ecosystem focuses on resource flows, sustainable production, and building consumption through CE strategies such as recycling and material reuse. Within this circular ecosystem, the actors' roles are determined by their assets and resources, and the actors are interdependent in the nexus of the local physical, economic, and institutional environment. The exchange of resources, energy, material flows, and information is one of the core principles of this circular ecosystem.

Based on these theoretical stances, this study assumes that a circular ecosystem of the built environment would consist of heterogeneous groups of actors, including, for instance, the local authorities, developers, contractors, service providers, and residents/ users that share the same value propositions and circular goals connected to a system-level product such as a building or living infrastructure. Under the multi-level perspective, each of the ecosystems can operate separately at the niche level, but these ecosystems may interact, be interconnected and influence each other at the regime level (Walrave et al., 2018).

Regarding the actor perspective, start-ups have gained more attention in the research of circular ecosystems. Large firms have plentiful resources but are often trapped in organisational inertia, so they usually adopt marginal circular strategies or incremental innovations (Henry et al., 2020). In contrast, start-ups are more creative and likely to introduce radical innovations and new circular business models (Hockerts and Wüstenhagen, 2010; Henry et al., 2020). With their creativity and distinctive evolutionary paths compared to established firms, startups are believed to be the crucial contributors to CE dynamics to create technological shifts and significant impacts on market structures (Henry et al., 2020; Huynh and Rasmussen, 2021). Collaboration between large firms and start-ups would benefit knowledge acquisition, enhance essential capabilities, and co-create circular ecosystem innovations (Henry et al., 2020; Evertsen et al., 2022).

The actor collaboration in a circular ecosystem has been highlighted as a prerequisite for achieving the CE within the built environment. However, a comprehensive examination of the distinct roles of all actors and how they should collaborate horizontally and vertically in the value chain remains lacking in the literature (Leising et al., 2018; Mhatre et al., 2021). Moreover, the significant roles of new actors and market entrants as the driving force for the circular building ecosystem have also been overlooked.

Among very few studies related to this topic, Volk et al. (2019) classified and compared the efficiency of material stocks in buildings and infrastructure by four main stakeholder groups (i.e., public authorities; clients and owners; planners and construction companies; and waste demolition, disposal companies, and construction material manufacturers). Nussholz et al. (2024) shed light on digital startups in the circular building environment. However, there still exists a significant research gap in the circular ecosystem of the built environment where the complexity and dynamics of multi-actor collaborations should be better explored.

Notably, the actors in the built environment often have conservative risk-averse mindsets and do not effectively collaborate horizontally and vertically (Hart et al., 2019). One reason is the low economic incentives for CE-related construction businesses. In theory, reusing materials and products should result in saved costs because reused materials may pose higher quality risks and potentially have shorter lifespans than virgin materials. However, this theory may not always hold to the built environment, which often has reused building materials with higher total costs due to labour-intensive processes (e.g., collection, processing, and recovery of post-materials) and reverse logistic costs (e.g., warehouse and transport) (Osei-Tutu et al., 2022). Besides, products made from reused materials may further require complex remanufacturing, ultimately leading to higher costs than primary products (Nußholz et al., 2020; Osei-Tutu et al., 2022). These disincentive factors would significantly affect the dynamics of actor collaboration in the ecosystem.

Moreover, regulatory safety, quality, and energy efficiency requirements also concern the actors (Hart et al., 2019; Knoth et al., 2022). The combination of low-profit margins and higher costs associated with reused materials leads to a conservative business mindset of the actors prioritising short-term economic interests over long-term circular benefits (Hart et al., 2019).

The technological gap for material recovery and material recycling has also been emphasised in the current literature, or the lack of technological solutions results in a lack of information and traceability of reused materials (Hart et al., 2019). Lacking supportive policies and

[1] Sustainable and circular construction. A Policy Brief from the Policy Learning Platform for a greener Europe (March 2024) by Interreg Europe.

regulatory frameworks may also hinder circular innovations in the built environment (Hart et al., 2019). This absence of regulations for standardising reused materials and obligatory circular adoption can intensify the friction in adopting CE among actors.

2.3. The policies for a more circular construction sector

Borrás and Edquist (2013) identified three main types of policy instruments: economic and financial instruments, regulatory instruments, and soft instruments. Regarding regulatory instruments, policymakers can use legal tools such as laws, rules, regulations, sanctions, and frameworks to regulate market and social interactions. Sanctions can also be used to force obligatory compliance. Additionally, monetary instruments, including positive incentives (e.g., subsidies, loan guarantees, reduced interests and tax), disincentives (e.g., taxation, tariffs, and fees), and economic means by kinds (e.g., vouchers, private provision of goods and services under governmental contracts) are also commonly used. Finally, soft instruments function as non-compulsory, recommendatory, and non-coercive, such as voluntary contracts, non-binding agreements, and private-public partnerships.

These policy instruments can be utilised for different priorities, purposes, and contexts. On the one hand, regulatory instruments are significant in defining a new market, regulating actor behaviours, forbidding environmental harm, and strict protection such as intellectual property rights. On the other hand, monetary instruments are often used to reinforce the supply side and innovation development. However, with the increasing significance of the demand side, financial instruments have also been more widely used to strengthen green products and environmentally friendly behaviours of consumers. Lastly, as recently emerged instruments, soft instruments are used more widely to fill the gaps that the traditional regulatory and monetary instruments cannot fully address. Previous studies have recommended a 'policy-mix' approach, combining policy instruments on both demand-side and supply-side to achieve comprehensive effects (Borrás and Edquist, 2013).

In recent years, the European Commission and European countries have enacted drastic measures to promote a more circular construction sector and aim to create Europe with low CO2 waste emission and low energy consumption. The European Commission has focused on primary aspects such as design for disassembly, material reuse and recycling, resource efficiency, energy efficiency, circular business models, and digitalisation and data management. Table 2 summarises an overview of circular construction policies enacted in Europe and Norway.

2.4. The norwegian context

In this study, we investigate the context of the Norwegian built environment. The construction and real estate industry is the second largest in Norway, with about 59,150 registered companies and 246,000 employees in 2017 (Statistics Norway, 2019). About 99 % of construction businesses are small and medium-sized companies in Norway (Statistics Norway, 2019). Among all sectors, the construction sector is one of the most significant contributors to total waste, which has continuously increased since 2016 (Statistics Norway, 2021). In 2022, Norway released a total of 2,11 million tons of waste from construction, rehabilitation, and demolition (Statistics Norway, 2023). Between 2004 and 2022, the waste from building and construction in Norway has nearly doubled (1,39 million tons in 2004 compared to 2,11 million tons in 2022), and the most significant increase (about 23 %) in building waste is from demolition, accounting for 43 % of all construction waste (Statistics Norway, 2023, 2024). Even though most of the waste from construction activities is uncontaminated materials that can still be reused without special environmental considerations, only about 45 % of total material waste was sent to recycling, and there has been no increase in material recycling since 2020 (Statistics Norway, 2021).

In Norway, about 10,000–22,000 buildings are estimated to be

Table 2
The overview of the circular construction policies in Europe.

Instrument categories	Policies
Regulatory instruments	**Circular Economy Action Plan/ EU Green Deal (2020); Sustainable and Circular Construction Policy (2024);** A Renovation Wave for Europe (2020): provide a framework, regulations, and successful examples of CE transition within the sector. https://www.interregeurope.eu/sites/default/files/2024-03/Policy%20brief%20on%20Sustainable%20construction.pdf https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en **New European Bauhaus (NEB)**: provide tools and guidance, engage stakeholders to collaborate, offer tailor-made solutions to shape circular ecosystems and transform the value chain. https://new-european-bauhaus.europa.eu/index_en **Waste Framework Directive (2024):** obliged to reuse, recycle, and recover 70 % of non-hazardous construction and demolition waste by 2020. The new target will be set by the end of 2024. https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en **Energy Performance of Buildings Directive (EPBD) and Energy Efficiency Directive (EED):** fully decarbonised building stock by 2050 https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en **Construction Product Regulation (CPR)**: requirements for the declaration of performance and circular economy marking of construction products in accordance with performance criteria of health, safety, and environment, as well as improving digital product information. https://single-market-economy.ec.europa.eu/sectors/construction/construction-products-regulation-cpr_en
Monetary instruments/ regulatory instruments	**Taxonomy regulation (EU Taxonomy):** classify sustainable economic activities aligned with the EU net-zero trajectory by 2050 and direct capital investments toward sustainability, circular economy, and environmental and climate protection. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
Monetary instruments	**Increased European and national research funding and grants for research activities related to CE** (EUR 95.5 billion under two Missions: Climate Neutral and Smart Cities and Adaptation to Climate Change, 1,35 billion to the Circular Economy and Quality of Life subprograms for the period 2021–2027). https://op.europa.eu/en/publication-detail/-/publication/1f107d76-acbe-11eb-9767-01aa75ed71a1 **Green loan and mortgage financing/ Mortgage Credit Directive and the Consumer Credit Directive:** provide favourable loans and financing for sustainable new construction and renovation
Soft instruments	**Level(s)**: provide a common language and extensively tested system for assessing and reporting on the sustainability performance of the building from design to end-of-life and applying CE principles in the built environment. https://environment.ec.europa.eu/topics/circular-economy/levels_en **One-Stop-Shop (OSS):** match the demand and supply and provide advice and financing solutions for homeowners and SMEs in the renovation.

Source: European Commission (ref: https://build-up.ec.europa.eu/en/resources-and-tools/articles/circular-construction-and-materials-sustainable-building-sector) demolished annually (Statistics Norway, 2021). This wastes many reusable materials and components in demolition instead of being disassembled and reused. Many buildings are demolished before the lifecycle ends, leading to still usable heavy materials such as steel and cement ending as waste.

The CE for the construction sector has been placed centrally in Norway's national strategic plans by the Norwegian government (2024). In 2022, Norway has increased the obligatory construction waste sorting from 60 to 70 % (The Norwegian Government, 2024). Furthermore, some actors in the industry have pioneered the promotion of CE in construction. For example, the pioneering Kristian Augusts Gate 13 project could reuse up to 80 % of the total weight of materials for the new building project and reduce carbon emissions by up to 70 % (Grønn Byggallianse, 2024). By reusing about 1000 tons of reclaimed granite collected from various suppliers and projects, the circular project "Vollebekk Torg" in Oslo has achieved clear circular goals of reducing 232 tons of waste, 248 tons of carbon emissions, and saving 1,2 million NOK for the developers (Grønn Byggallianse, 2024). Given the prevalent challenges and ongoing CE efforts, the Norwegian built environment presents an intriguing and pertinent empirical context for this study.

3. Methodology

3.1. Research design

This study adopts an exploratory and inductive approach to examine the circular built environment at a system level. An exploratory case study "explores the situations in which the intervention being evaluated has no clear, single set of outcomes." (Baxter and Jack, 2008, p. 548; Yin et al., 2012). This method is suitable for this study to examine a contemporary phenomenon because (a) the behaviours of the actors in the research are not subjected to be manipulated by the research, and (b) the contextual conditions are essential for the phenomenon of the research (Baxter and Jack, 2008; Yin et al., 2012).

Furthermore, by comparing cases to identify empirical evidence for literal replication (i.e., cases with similar results) and theoretical replication (i.e., cases with contrasting results), the multiple-case study method can also be used to explore the differences and similarities within a case or between several cases (Stake, 2013). The multiple-case study method "illuminates a decision or a set of decisions: why they were taken, how they were implemented, and with what results" (Schramm, 1971, p. 6).

The multiple-case study method has a significant effect on this study by comparing and illuminating the heterogeneities in the distinct groups of actors (e.g., developers versus contractors and users) and the different actors in each same group (e.g., small versus large developers and municipalities; large construction firms versus start-ups). The multiple-case study also allows the discovery of new insights about actor collaboration patterns and new actors (e.g., material reuse marketplace providers and CE advisers) that might still need to be explored in the literature.

3.2. Data collection and data analysis

This study uses primary data (i.e., interviews) and secondary data (i.e., news articles, website information, reports, and online recorded workshops and seminars). Contrary to surveys presenting primary data in numerical and succinct text formats, interview techniques can explore more extensive, nuanced, and intricate information, revealing previously undiscovered insights.

The primary data of this study is collected through 19 interviews with new and existing critical actors in diverse groups, including municipalities, public developers, private developers, research organisations, contractors, public-private partnership organisations, architect & engineering consultants, startups, cluster organisations, material producers, and CE consultants. Because our study is part of a large research project/ research centre with a rich network of key companies and actors in Norway, we selected most respondents from this network. We also used the snowballing technique to get introduced further by interviewees to other vital actors. Our respondents cover all types of actors in the sector. We also carefully consider the diversity in respondent groups to obtain the nuance in our research understanding. For example, we approached and interviewed both private and public developers, small/ medium/ and large-sized municipalities and developers, small and large contractors, and other groups of actors. Table 3 provides the profiles of the interview cases.

interviews are semi-structured, and the interviewees are asked open-ended questions and encouraged to freely share their views and insights. Based on the provided information, the interviewers then delve deeper into the subject matter by asking follow-up questions, such as "Why did you consider doing that?" or "How did you do that?". This interview technique is rooted in the narrative approach (Polkinghorne, 1988; Czarniawska, 1997). It allows interviewees to openly share their opinions and recount experiences closest to the actual events with minimal interruption or biased intervention from the interviewers. The interviews were conducted within 45–60 min via physical or digital meetings from January to February 2024. All the interviews were recorded and fully transcribed for coding and analysis.

Furthermore, we also adopted triangulation of data, investigator, theory, and methodology to ensure research reliability. First, data triangulation involves the use of different data sources and types. Our study combines primary interview data with diverse secondary data sources from workshops, reports, and news articles. We attended three online seminars and workshops. Each workshop lasted about two to three hours and was presented by experts in the field.

We also conducted content analysis on sixteen practitioner reports written in 30–100 pages by different actors such as research institutes, companies, consultants, and governmental organisations. These reports are focused on the relevant topics related to 'material reuse in practice, 'building waste management,' 'feasibility studies of CE construction projects,' 'final report of circular construction projects,' 'digital market platform for material reuse,' and 'reuse mapping and planning'. These combined data sources give us the closest understanding of the CE in European and Norwegian practices.

Second, theory involves considering the fit of data with different explanations and theories. In our research, we reflected on identifying similarities or dissimilarities between our empirical results and theories. In that way, we could better explain the heterogeneities attributed to the context and phenomenon we examined.

Third, investigator triangulation is achieved when more than one person conducts the interview, or the same interviewer approaches the subject on different occasions. In this study, we involved two researchers in conducting interviews and discussing interview results. Finally, methodological triangulation is achieved using various methods in the same study. Qualitative research usually uses two or more forms of collecting data, such as interviews and observations. Hence, we combined the interviews with observation through workshop participation.

3.3. Data coding and analysis

This study adopted the analysis framework proposed by Wolcott (1994), following a structured approach comprising four sequential steps. Initially, a comprehensive review of transcripts and documents was conducted to extract the overarching themes. Subsequently, relevant themes were identified and highlighted from the literature, while irrelevant details were filtered out.

Then, recurring patterns within the coded data were identified and clustered into cohesive themes and categories. In the interview, we focused on the themes: (1) the roles of the actors in the CE, (2) circular strategies/ circular projects, (3) collaborative partners & patterns, (4) barriers & drivers, (5) market, and (6) enabling technologies. To ensure clarity of the interpretation, Creswell and Poth (2016) suggested limiting the category numbers to no more than thirty and themes to five

Table 3
The profiles of interview cases.

Category	Actor	Interviewees	Profile
Municipality/ public developer	Municipality A	Advisor/project leader	Large size municipality (about 250,000 population).
	Municipality B	Advisor/ project leader	Middle-small sized municipality (about 45,000 population)
	Municipality C	Advisor and engineer	Small-sized municipality (about 20,000 population).
	Municipality D	Advisor/ project leader	Large size municipality (about 200,000 population)
Private developer	Developer T	Project leader	A leading private developer focused on private housing.
Contractors	Contractor E	Assistant project leader	A leading contractor with more than 6000 employees collaborating with developers and subcontractors.
	Contractor F	Advisor chief	One of the world's largest contractors. The Norwegian branch has more than 4000 employees.
Architect consultant	Architect consultant H.	Advisor/ engineer	A small Norwegian consultant established about 35 years.
Startups/ digital market platform	Start-ups I	Founder	A startup provides digital platform services for material reuse
Startups/ warehouse provider	Start-ups J	Co-founder	A startup provides physical warehouse services for material reuse
Startups/ technology provider	Start-ups K	Founder	A startup provides blockchain technology services
Startups/ technology provider	Energy service supplier L	Business development chief	A small-medium service provider with about 135 employees.
Material producer	Material supplier M	Product manager	A global leading manufacturer of chemical products for the building industry.
CE consultant	CE consultant N	Advisor	A CE consultant organisation is focusing on mapping material reuse.
	CE consultant G	Advisor	A key CE consultant organisation in Norway owned by both public and private organisations, it has successfully led and demonstrated circular projects in Norway.
	CE consultant O	Co-founder	A CE consultant organisation focuses on material market banks.
Cluster organisation[2]	Cluster organisation P	Business developer/ project leader	A local cluster organisation.
Research organisation	Research organisation S	Senior researcher/ project leader	A leading research institute in Norway and Europe.
	Research organisation S	Researcher/ project leader	A leading research institute in Norway and Europe.

[2] A local chamber of commerce organisation (over 150-year-old) consists of 1950 business members in the local. The organisation frequently provides local business members with training, courses, networking events and advice and participates in research projects funded by the Norwegian Research Council.

or six, regardless of the sample sizes. This coding and categorisation process serves as the groundwork for theoretical interpretation. We summarise several examples of topic themes, direct interview quotes and coded terms (see Table 4).

In the final stage, categories were systematically labelled to delineate similarities and differences. For example, we compared the four municipalities and identified their differences in distinctive sizes and geographies. In addition, we compared the two pairs of municipalities and developers of similar sizes. We compared these municipalities in our data with counterparts in other reports to ensure the consistency and generality of our findings. Orton's (1997) analytical technique was applied to interpret the observed data, facilitating the connection

Table 4
The examples of coding.

Respondents	Direct interview quotes	Coded terms– level 1	Categories
Municipality B	*"It is* ***more challenging here because it differs from large cities*** *in South Norway. We have* ***few actors*** *in this area. So, it's not much competition. If we push (CE goals) too hard, the contractors* ***don't*** *feel comfortable* ***taking the risks and raise the price*** *a lot because of the risks. So, finding a* ***balance between economy and CE goals is very hard.****"*	It is more challenging than in large cities. There are few actors in the area. (contractors) do not take risks and increase prices. Challenging balance economy and CE goals.	Small municipality. There are a few supplier options locally. Low negotiation power. Balancing economic and CE goals.
Municipality B	*"It's a lot about* ***sharing responsibility*** *and* ***risks for builders and contractors*** *to increase the incentives for material reuse…* ***Models for risk sharing*** *are very* ***important****, I think,* ***to reduce the risks****, for example, by using* ***contract and procurement system.****"*	Sharing responsibility and risks for both builders and contractors to increase incentives. The risk-sharing model is essential to reduce risks. Using contract and procurement systems.	Sharing responsibility and risks. Both builders and contractors. Risk models. Contract. Procurement system.
CE consultant G	*Our main role is primarily to work with* ***pilot projects and drive innovation*** *through projects. We* ***collaborate with developers****. They come to us with their* ***ambitions for green and circular projects****.*	Collaborate with pilot projects and drive innovation through projects. Collaborate with developers with ambitions for green and circular projects	New actor roles. Collaboration partners.
Start-ups I	*To get donated materials, we* ***need a large network to access secondhand materials and a layer of trust****. We had* ***material donors who changed their minds*** *and took back half of it. It creates* ***much unpredictability*** *because of* ***the lack of formal responsibility****.*	Need a large network and a layer of to assess secondhand materials. Material donors changed their mind. Unpredictability. No responsibility.	New actor roles/ reuse material marketplace. Challenges. Collaboration patterns.

between theoretical frameworks and empirical findings, and enabling a deeper understanding of identified patterns within and across categories.

4. Findings

4.1. The circular processes and actors

Based on the literature and data, we analyse and describe the circular ecosystem of the built environment, comparing the traditional linear model with the new circular model. Moreover, we conduct a mapping of the actors with the complete CE processes. The linear construction model includes the following conventional stages:

- Concept development: based on the needs, the owner/developer decides if the building should be built as new, refurbished, reused, or demolished.
- Design: the architect and construction solutions are decided and detailed in designing, modeling and documenting.
- Product and material production: based on the solutions, materials decided in the design stage are procured and produced.
- Construction: the building is constructed and ready-made for use.
- Operation: the building is in use and generates value for its users and owners. This is the longest stage in the lifetime of a building and requires maintenance to function well.
- Demolition: the end of life (EoL) where buildings will be demolished and deposited as construction wastes into landfills.

The new CE processes add new stages:

- EoL building report & reuse mapping: the EoL building may contain reusable materials and components. To extract reused materials, buildings need to be mapped and planned for reuse.
- Disassembly (substituted for demolition): reusable materials with usable quality are disassembled from the EoL building.
- Reused material collecting: the disassembled materials are collected from the site.
- Reused material processing: some reclaimed materials must be processed and recycled before reuse.
- Reused material testing & documenting: some reclaimed materials must be documented or evaluated.
- Material bank and storage: reused materials are stored and sold by physical or digital material banks, while some materials are transported directly to a new site for immediate reuse.
- Reused material delivery & reuse: reused materials are delivered and ready to use.

Fig. 1 presents a detailed mapping of the entire CE building processes with the involved actors at each stage. Two main flows are identified in Fig. 1: the material flow, where actors are directly involved in the building process, and the knowledge flow, where information and knowledge are transferred among the actors. The dot lines between Stage 2, stage 5, and Stage 6 mean that the integration between design, operation and material reuse mapping has been started but still not fully established.

Furthermore, we distinguish between the direct and indirect actors of the circular building ecosystem. The direct actors (e.g., developers/building owners, municipalities, contractors, suppliers, startups, consultants, and waste management firms) play direct roles in making decisions and participating in various circular building processes. Additionally, the indirect actor group (e.g., building users, financial institutions, and academic organisations) may not be involved directly in the operation and construction activities. Still, they are an essential part of the circular ecosystem.

Moreover, the actors can also be distinguished as the existing and new. Most new actors (as illustrated in Fig. 1) primarily participate in

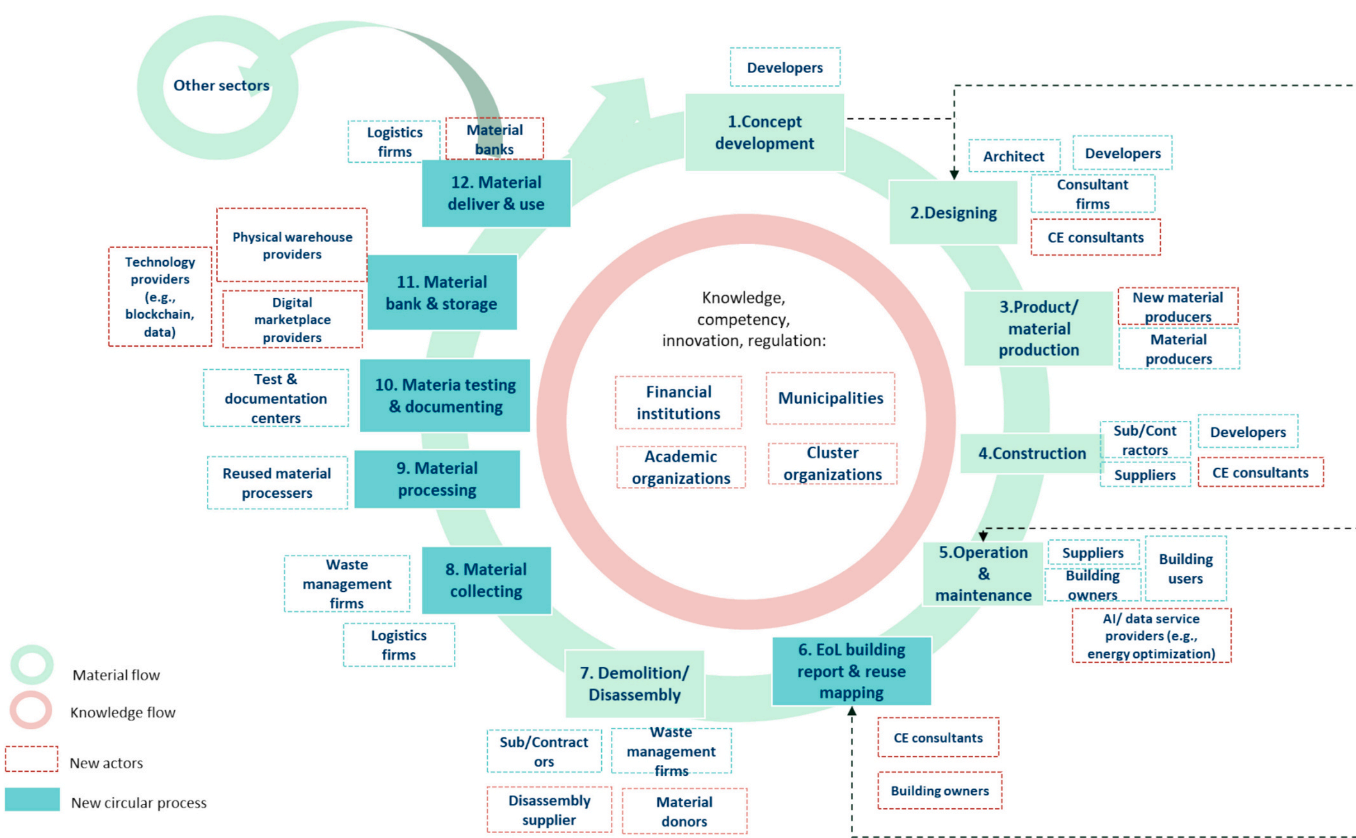

Fig. 1. The circular processes and mapped actors.

the latest circular stages of material reuse and AI-enabled energy optimisation. We summarise and compare the linear and circular processes with the key existing and new actors in each process in Table 5.

Contrary to prior literature claiming low awareness and interest of the actors in the built environment (Munaro et al., 2020), Norwegian actors show considerable interest and ambition in circular strategies, but circular intention does not always translate into actions and commitment. Furthermore, the CE knowledge and ambition are heterogeneous among the actors. The linear businesses appear significantly less complicated for the actors (e.g., ordering new materials online and receiving timely deliveries from available supplies), while the CE processes are significantly challenging. Table 6 summarises the key challenges each actor faces in CE construction.

4.2. The activities in the circular building ecosystem

Actor collaboration is central to joint innovation development in a circular ecosystem. Knowledge sharing occurs between various actors, such as contractors and developers, startups and contractors, and consultants and developers. This knowledge transfer was organised formally (through workshops, training sessions, and seminars) and informally (through project collaborations). Several key actors (e.g., Municipality A & D, Contractor E & F, Consultant N, and Cluster Organisation P) actively participate in research projects, seminars, and workshops to share know-how and practical experiences. This activity elevates the joint circular capacities and shared goals among the actors.

New business ventures often emerge as spin-offs from large firms (e.g., the case of Startup I), as public-private partnerships (e.g., the case of Startup K, Public-Private Organisation G), or as local initiatives from municipalities (e.g., the case of CE Consultant O, Public-Private Organisation G).

Our data also suggest that system innovations jointly developed by the actors are essential to a circular built environment. These innovations are co-created and co-developed through diverse forms of collaboration (e.g., research projects, business projects, or innovation development projects) and spread through various actors, including private sectors (e.g., startups, contractors), public sectors (e.g., municipalities) and academic partners (e.g., research institutes).

For instance, a new business model and service resulted from a collaborative public-private business project when Municipality A collaborated closely with a local startup to establish a physical warehouse of reused materials for private builders in the region. Another example involves collaborative research projects by contractors, research institutes (Research Organisation S), and municipalities to explore the application of reused expanded polystyrene material in the sector and across other sectors.

Municipalities play pivotal leading roles in stimulating circular innovation activities in their local regions. Municipalities can take two simultaneous roles as both public developers and authorities. As public developers, municipalities are directly involved in the decision-making processes of circular strategies and collaborate with partners in the value chain. They also coordinate with new service providers to reduce existing buildings' energy consumption and increase the tenant's well-being. As local authorities, municipalities play active roles in establishing frameworks and criteria for circular building projects involving material reuse or design for disassembly.

Moreover, Municipality A and Municipality D significantly contribute to circular innovations and knowledge transfer with other smaller municipalities in different ecosystems. Most circular innovation initiatives led by municipalities are often geographically proximity-oriented and locally organised.

In line with the literature, our study also finds that new actors, such as technology companies, drive radical innovations and technological changes. These startups (e.g., Startup J, Startup K, and Energy service supplier L) also hold significant roles in identifying and filling market gaps and creating niche market segments with new circular services and

Table 5
The comparison between linear versus circular processes in mapping with the actors.

	Linear processes	Circular processes	Key actors
Material production	• Extract primary materials. • Process and produce products from the materials.	• Replace with sustainable, renewable materials. • Recycling materials. • Integrate material pass using blockchain technology to input information on materials and products.	• **Existing actors:** material producers • **New actors:** reused material processors
Concept development, design & planning	• Conventional design and • planning using primary materials.	• Design for material reuse. • Design for disassembly. • Design for intelligent energy optimisation. • Design for repairing. • Select more renewable and sustainable materials.	• **Existing actors**: developers and architect consultants • **New actors**: CE consultants, material bank
Construction	• Construct new buildings.	• Construct with energy efficiency and material reuse. • Construct or renovate with reused materials.	• **Existing actors:** developers, contractors, sub-contractors, and suppliers • **New actors:** CE consultants
Operation	• Operate buildings. • Repair and maintenance.	• Repair buildings by 3D printing. • Optimise energy and resource efficiency. • Monitor, control, and optimise energy consumption and GHG emissions using data-driven models. • Improve the well-being of building tenants.	• **Existing actors:** building owners, suppliers, building users. • **New actors:** AI/data-driven service providers.
End of life	• Demolish buildings after the end-of-life cycle. • Deposit construction wastes into landfills for incineration.	• Disassemble buildings for material reuse and recycling. • Operate market banks (digital and physical) for the material reuse market. • Test and document reused materials. • Recycle construction wastes as inputs for other sectors.	• **Existing actors**: waste management firms, contractors, suppliers • **New actors**: building mapping consultants, material donors, disassembly suppliers, technology providers, material bank, material processing, testing & documenting centres

Table 6
The summary of the roles and challenges of the actors.

	Roles	Challenges
Developer	Develop new or renovating projects with CE concepts. Integrate design for disassembly and design for energy efficiency.	Limited budget and timing that may not fit material reuse. Low interests and lack of collaborative attitudes from partners. Small-sized private and public developers have limited negotiation power with contractors.
Municipality, local authority	Organize knowledge area and market dialogue to promote CE in locals.	Lack of know-how knowledge. Lack of supportive CE policies and frameworks.
Architect & consultants	Consult, design, and provide solutions for material reuse or resource efficiency.	Lack of expertise knowledge for circular designs/ design for disassembly and resource efficiency. Lack of standardised procedures and methods for condition assessment for reclaimed components and materials leads to material reuse risks. Lack of legalisation for making decisions on the reuse of components
Contractors, supplier	Implement CE practices in construction, maintenance, and operation.	Risks of material reuse (e.g., project delay, material quality and safety, reused material supply). Restraint budget and profitability.
Building owner/ building donor	Donate reclaimed materials and components.	Lack of expertise knowledge in EoL building reports and reuse planning. Higher costs of disassembly instead of demolition.
Cluster organisation, public-private organisation.	Create dialogues, training, and knowledge arena for actors. Provide guidelines and criteria mapping. Push and initiate circular innovations in the sector. Transfer and share "know-how" knowledge among actors.	Lack of supportive CE policies and frameworks. Lack of operational funding.
Startup	Offer product and service innovations (e.g., material bank, material passport (blockchain-based), data-driven energy efficiency, or disassembly services).	Small niche market and unable to scale up markets. Market immaturity and uncertainty. Low market demand and market volume. Deficiency in resources such as financial resources and networks.
Research partners	Develop innovative technologies and circular innovations through research projects.	Research knowledge cannot be commercialised and upscaled in the market. Lack of research funding.

products (e.g., AI-enabled material mapping, digital market platform or blockchain-based product passport).

However, the CE market is still evolving and will demand more new actors, circular startups and suppliers. The emerging CE processes highlight the need for new services such as material testing, documentation, building disassembly, and EoL building and material mapping.

4.3. *Mapping the actor networks by CE principles*

Based on the three main CE principles, which have widely been used in the literature as a theoretical framework (Bocken et al., 2016), we provide a network mapping of the involved actors in the CE principles. Each CE principle may entail diverse activities and CE strategies. For example, closing the loop can be achieved by not only recycling and regenerating materials into other inputs but also by reusing materials from EoL buildings. Likewise, narrowing the loop can simultaneously be achieved by reducing resource consumption or replacing it with sustainable materials and energy.

4.3.1. *Closing the loop: material reuse and recycling*

Closing the loop by material reuse and recycling is one of the key strategies to create a closed-loop built environment. Material reuse plays a central role in minimising waste emissions and reducing the new exploitation of primary materials.

The circular building process is initiated with the design and planning phase. Traditionally, architects would design and then look for suitable reused materials. However, the new paradigm toward material reuse necessitates a more proactive approach. In a new circular process, architects, and CE consultants (i.e., CE consultant N, CE consultant O, Architect consultant H) should actively collaborate to explore the feasibility of design for disassembly and material reuse.

The developers, architects, and contractors must interact closely in the circular ecosystem. Nevertheless, their collaborations are associated with conflict and friction during the circular processes. Risks related to material reuse are considered one of the most significant disincentives for most actors (e.g., municipalities, developers, contractors, startups, and suppliers). Almost all the interviewed actors mentioned 'risk' at least once or several times. This implies a significant concern among the actors about the risks of circular construction activities. To implement circular projects, all participating partners must be willing to share the potential CE risks, such as project delay, higher costs, or lack of supply sources. Thus, the CE incentives are the result of the actor's willingness to navigate and manage these risks collaboratively.

Although most developers and contractors may be initially interested and aware of the CE, they eventually withdrew from material reuse goals in some cases. For example, Municipality C shared that they experienced a situation when developers initially expressed significant interest in material reuse but eventually withdrew due to concerns about higher costs and risks of delay. Another municipality experienced that the developer was ambitious in implementing CE but was refused by the contractors due to high risks of responsibility and low profits. This illustrates the complexity of balancing short-team economic goals with long-term circular benefits in the construction industry.

Moreover, we found that several CE-forefront developers and contractors have collaborated with recently emerged CE consultants to receive CE guidelines for material reuse and mapping. This is because building materials contain many different technical specifications, lifecycle characteristics, and market attributes. These consultants would provide CE advice and conduct planning reports of buildings at the EoL stage and reusable materials. These reports can subsequently be shared with material bank partners to facilitate material collecting. These CE actors make a bridge between material banks and building donors, establish criteria and guidelines, and match the demand and supply of material reuse markets.

In the evolving prospect of material reuse models, the new actors (e.g., digital market platform providers, physical warehouse providers, reused material processors, and test & documentation centres) collaborate closely in the new circular processes. Material Supplier M shared that material recycling firms should establish better connections with primary material producers to deposit reclaimed materials back to the value creation cycle of material production. Additionally, waste management firms may be able to expand businesses or collaborate with new actors in processing, recycling, and handling logistics of reused materials.

Although collaboration with new market entrants may benefit large firms, some well-established actors may perceive new circular business models as threats instead of opportunities because new products and services may undermine their traditional market segments. Thus, to be prepared for market disruption, these actors should adapt their mindset and business toward CE and material reuse. New actors, such as the material banks, may continue to evolve and become more significant in the upcoming years.

Furthermore, the role of private builders should be reinforced as mentioned by Startup I. In addition to business-to-business segments, private renovations can increase the demand for surplus or reused materials. So, the business model for private builders should be considered a significant market niche, and reused materials for private builders should also be listed on the digital marketplaces. Additionally, Private Developer T highlighted that financial institutions such as banks can influence circular construction practices by issuing green loans for circular projects. This approach also helps increase circular adoptions in the built environment by improving economic incentives for the actors.

Finally, Research Organisation S highlighted that the sector still needs more efficient collaboration between actors in the construction sector and other sectors to close the waste stream. This is partly due to a lack of industrial dialogues and research on the application and revenue models of waste-as-inputs between industries. Local municipalities need to facilitate this network between the building sector and other sectors to increase the efficiency of resource exchange. Fig. 2 visually represents the intricate connections between actors involved in the 'closing the loop' principle.

4.3.2. Slowing the loop: maintenance, renovation, and repurposing

Slowing the loop entails maintaining, repairing, renovating, and repurposing building utility. Municipality B emphasised reusing and recycling materials after EoL buildings and maintenance and renovation for the longest lifecycle of buildings. In addition to conventional activities such as building maintenance and renovation, new CE processes also necessitate more proactive thinking approaches by integrating design for repairing, disassembly and repurposing in the early phases of concept development and design.

Several actors in our data (e.g., Contractor F and Research Organisation S) have implemented building projects involving design for disassembly where building components and elements are designed to be more easily disassembled for repairing and replacing, for example, by using screw and bolt instead of nails techniques. Advanced technologies such as AI and robotics may also enhance this process by automatically identifying malfunctioning conditions, replacing them with new components, and preserving the building in good condition.

In the conventional linear process, the stages of concept development/ design and operation (i.e. maintenance) tend to be separated and have little connection between the concept developer, designer, and operators. However, as illustrated in Fig. 1, this link between these actors should be more well established in the CE process, where the concept developer and designer should take more initiative in surveying with the operators the potential needs for maintenance so the buildings would be designed for easier disassembly and repair. Furthermore, during the design phase, the building utility should be considered for more diverse utility purposes. For example, a building is designed for a primary purpose, such as an office, but should be able to be converted to social housing after the end of the office utility.

We illustrate the links between the actors in the 'slowing the loop' in Fig. 3. It also shows that other actors, such as research institutions and local municipalities, have actively collaborated and enabled the new CE processes.

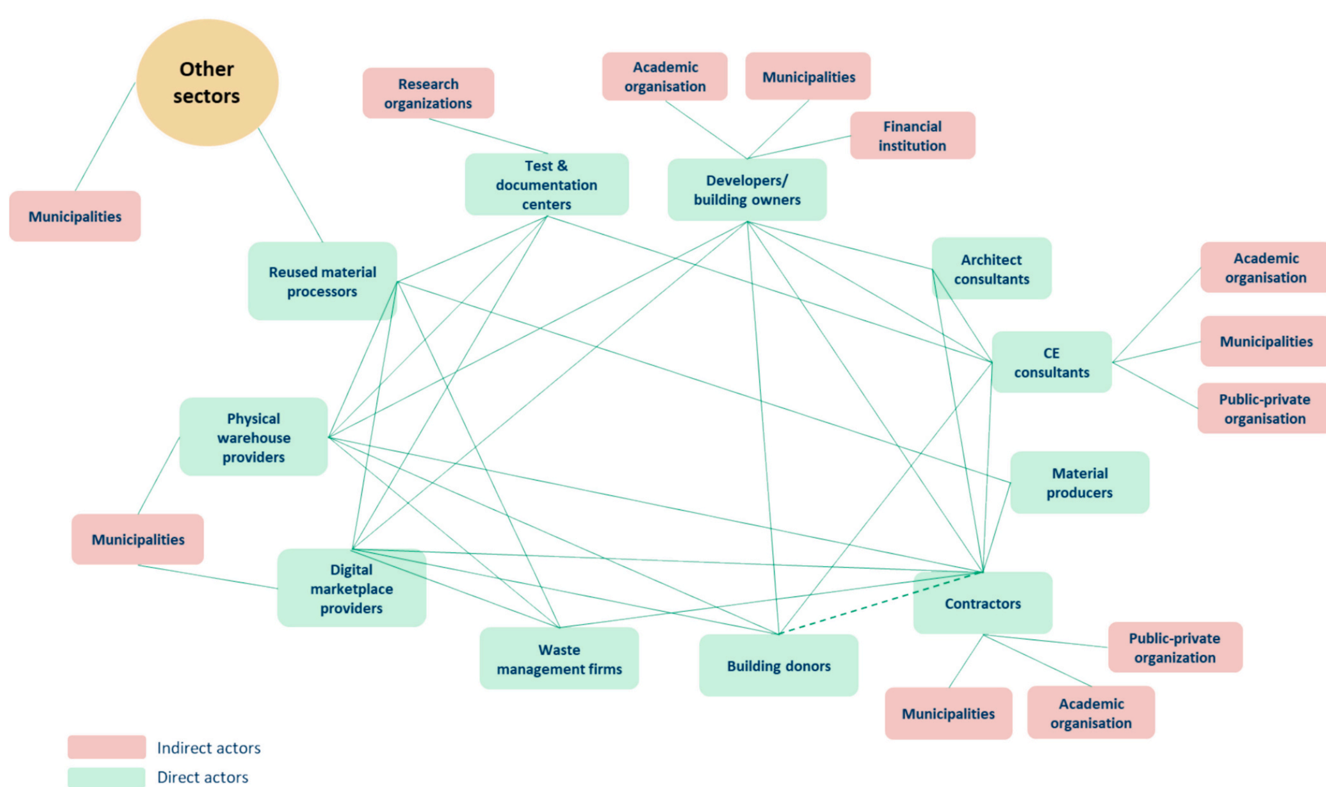

Fig. 2. The actor network in the 'closing the loop' principle.

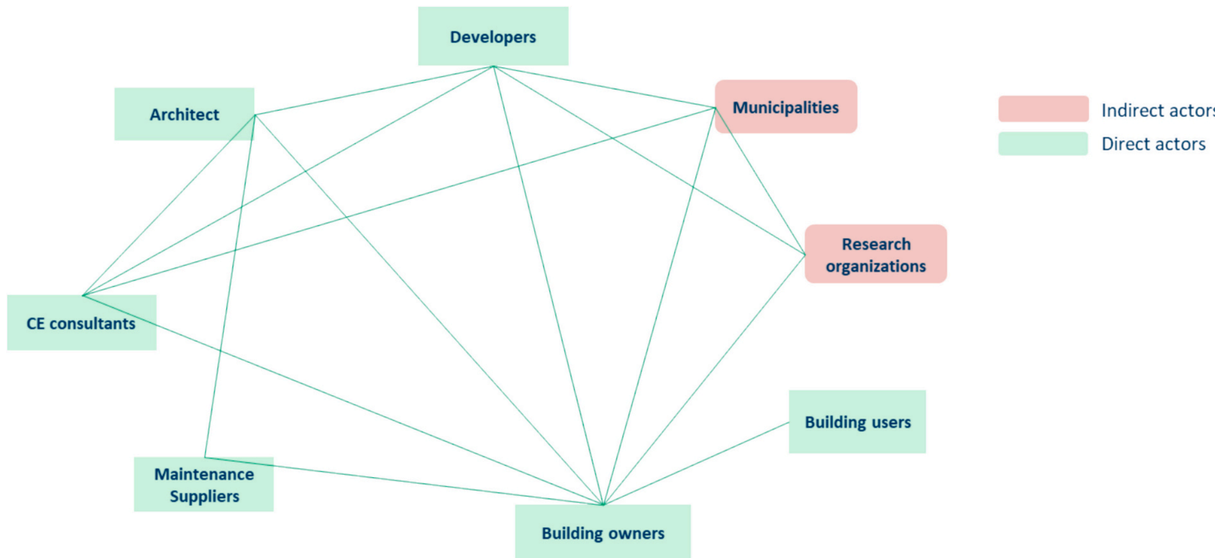

Fig. 3. The actor network in the 'slowing the loop' principle.

4.3.3. Narrowing the loop: resource and energy efficiency

Circular building entails not only reuse and recycling but also the efficient use of energy and resources (Nussholz et al., 2024). The 'narrowing the loop' principle is closely connected to seven critical principles, including energy efficiency, affordability, decarbonisation and integration of renewables, improved health and environmental standards, life-cycle thinking and circularity, tackling the twin challenges of the green and digital transitions, and respects for aesthetics and architectural quality (European Commission, 2020a). Municipality B emphasised that reducing the environmental impacts of the built environment through circular strategies is crucial not only for the design and construction phases but also for the operation phase.

The 'narrowing the loop' principle is primarily embedded in the design and operational stage by leveraging digital technologies (e.g., real-time big data, sensors, and the Internet of Things) to measure, predict, and optimise energy consumption during the operation phase of the building. This data-driven, intelligent energy distribution system involves stakeholders such as energy service providers, building owners, and users. Real-time data is collected and analysed by self-learning prediction models to optimise energy usage and promote health and tenants' well-being (e.g., the case of Energy Service Supplier L).

However, as also mentioned in the 'A Renovation Wave for Europe – Greening Our Buildings, Creating Jobs, and Improving Lives' (European Commission, 2020a, p. 1) that "most of the existing buildings are not energy-efficient" many existing buildings are suitable made for digital technology equipment. Most of these existing buildings rely on fossil fuels for heating and cooling (European Commission, 2020a). To address this issue, developers and building owners must integrate design for zero-emission and energy efficiency early in a new building project's design and planning phase. Future building or renovation projects should be designed for a digitalised CE with installable sensors for data-driven energy optimisation.

In addition to the energy stream, the 'narrowing the loop' in the built environment is also about the material stream. The design phase is highly essential to optimise material consumption (i.e., use less material) and select more environmentally-friendly materials (e.g., wood-based, polymer, and biomaterials) and renewable energies (e.g., solar energy, water energy) to decrease the consumption of fossil and non-renewable natural resources. Fig. 4 describes the links between the direct and indirect actors in the 'narrowing the loop' principle.

5. Discussion

The CE transition is a societal shift that alters the ecosystem of actors, technologies, and values. The circular ecosystem of the built environment is a comprehensive example of how all interconnected actors,

Fig. 4. The actor network in the 'narrowing the loop' principle.

whether direct or indirect, existing or new actors, need to collaborate closely to enable a radical socio-technical and economic paradigm shift toward a more circular construction.

5.1. Toward a collaborative circular ecosystem of the built environment

We contribute new insights into the ecosystem literature by illustrating how circular building ecosystems operate on the regime and niche level through actor collaborations. Based on theoretical stances, our study adds that circular ecosystems of the built environment tend to be positioned on the individual building project as the focal value proposition the actors share. In addition to project-centric attribution, each ecosystem is proximity-centric since the actors often collaborate locally.

Our study provides a new insight that at the niche level, the developer and the municipality act as the keystone actors collaborating with their involved partners, such as local contractors, local authorities, startups, CE consultants and other actors in the same circular ecosystem. Several keystone actors operate in different ecosystems simultaneously. For example, Developer 1 have several projects in the same city, or Contractor 2 can have other projects in other cities (see Fig. 5). The appearance of the keystone actors in different ecosystems allows knowledge spillover between the ecosystems.

Our study also finds the discrepancies in circular ambitions among actors in the same category, for example, between the public developers (e.g., Municipality) and private developers (e.g., Housing Company T). Compared to the larger counterparts, small and medium-sized contractors and suppliers have significantly lower incentives for CE, primarily due to their restraint profit margins and economic incentives that are prioritised beyond circular goals. Additionally, these smaller municipalities and developers (e.g., Municipality B or Municipality C) often have significantly lower negotiation power in dealing with a limited number of contractors or suppliers in local areas. Consequently, they may struggle to set ambitious circular goals in new projects. Finding a balance of circular ambition, the barriers of risk and price factors appear more challenging for smaller municipalities and developers.

Furthermore, we shed new light on the interaction of two or more circular building ecosystems through knowledge transfer activities of the keystone actors (e.g., municipalities and developers) (see Fig. 5). Knowledge hubs via frequent market dialogues, training, and workshops are effective for the 'know-how' diffusion and collaborative innovation initiatives within the circular systems on both the regime and niche levels. The effectiveness of a circular ecosystem depends on a continuous and rapid flow of information, data, and knowledge that actors are willing to share with others (Thakur and Wilson, 2023).

The actor collaborations in the circular building ecosystem need to be shifted from linear to more collaborative and multidimensional, namely bottom-up vertically (i.e., from startups/suppliers to contractors and developers), top-down vertically (i.e., from developers to contractors), and horizontally (i.e., between municipalities and startups).

The top-down and bottom-up systems of circular built environments are also aligned with the previous study of Joensuu et al. (2020). From our empirical evidence, bottom-up collaboration originates from startups and suppliers, transferring technologies and market solutions to contractors and developers. This collaboration dynamic may drive technological trajectory changes and disruptive innovation in the sector. Conversely, top-down collaboration stems from project developers who own substantial resources and can impose circular goals for contractors to implement construction projects.

Third, horizontal collaboration occurs between organisations at the same hierarchical level or the same technology domains, such as municipalities exchanging best circular practices or startups partnering to jointly develop new technical solutions. These lateral technology and knowledge exchanges foster constructive collaboration and accelerate circular innovation in the ecosystem. We illustrate the actor collaboration dimension of the circular building ecosystem in Fig. 6.

Lastly, from our findings, we highlight that all three CE principles adopted in the circular building ecosystem emphasise the importance of

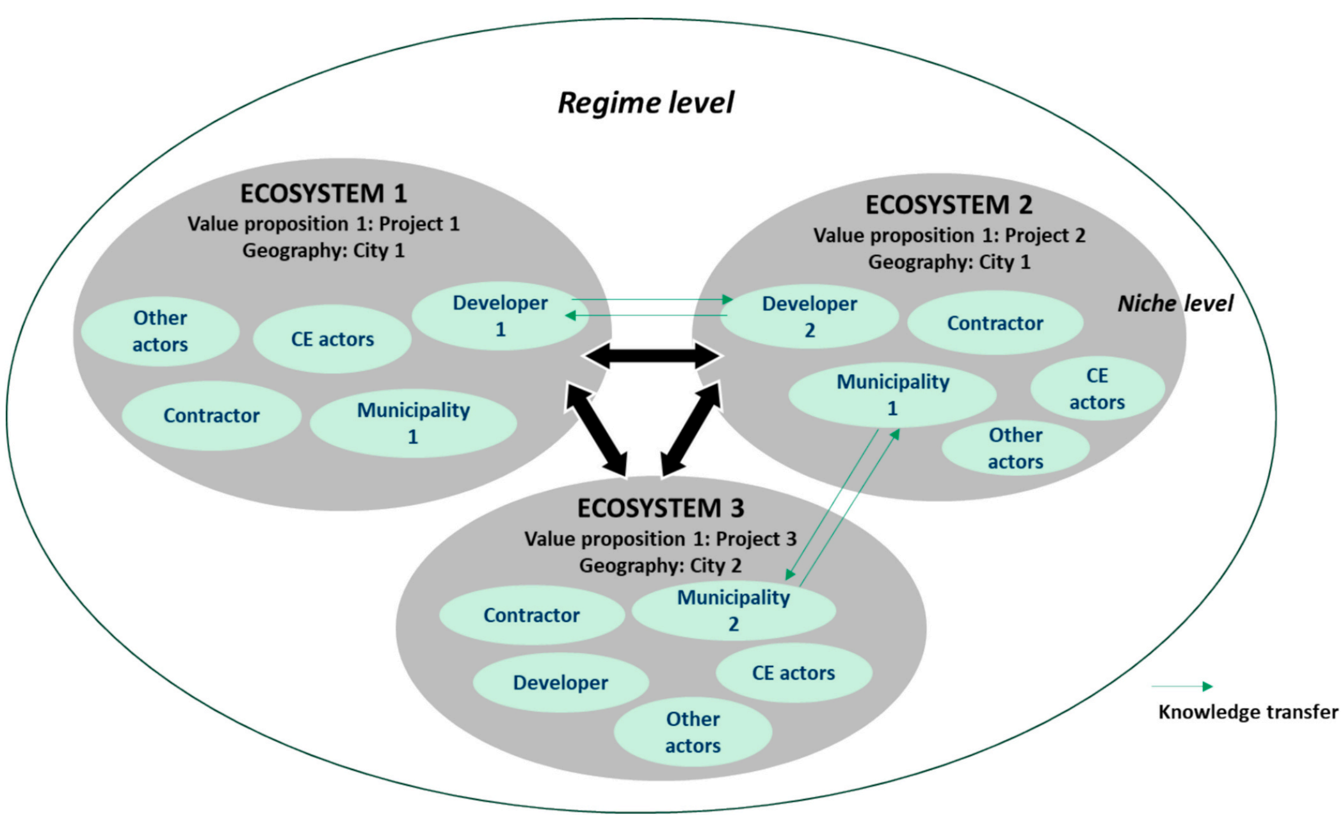

Fig. 5. The circular ecosystems of the built environment.

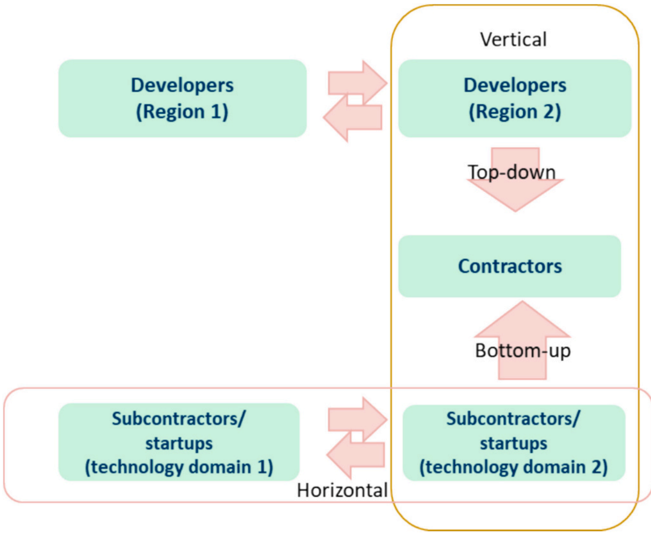

Fig. 6. Multidimensional actor collaboration in the circular building ecosystem.

early design for repair (slowing the loop), material reuse (closing the loop) and energy efficiency (narrowing the loop). This shows that the role of concept developers and architects is essential to integrate CE goals early from the concept development and design phase.

5.2. Actor incentives to reinforce collaboration dynamics in the ecosystem

Conflict and incentives strongly affect actor collaboration in the circular ecosystem. Risks emerge as a significant factor for conflicts, particularly among the direct actors such as developers, contractors, and architects whose economies and responsibilities would be significantly impacted by the unpredictability of the CE processes. High interdependencies between the directly involved actors in circular construction projects might lead to a higher probability of joint risks and responsibilities that consequently lower CE commitments.

Complementing to Dulia et al. (2021)'s study which pointed to primary risk factors such as recycling quality degradation and lack of mutual goals, our study delves more into specific risks in the phases of building project planning, operation, and project economy when the intricated risks (e.g., safety and quality of reused materials, potential delays in construction, cost inefficiencies, and insufficient supply volumes) are likely to occur. Compared to other sectors where reused materials might be cheaper than primary materials, reused building materials can be more expensive despite a shorter remaining lifetime.

We emphasise that a comprehensive risk assessment model and formal contractual means are needed to reinforce a more decisive circular action and commitment in the circular ecosystem. A risk model focusing on CE practices in construction is still lacking in the literature. It is critical to access and fully develop a risk management model and pricing structure as a foundation for circular contracts. Aligned with Konietzko et al. (2020)'s perspective, we highlight the need for circular contractual agreements with clear value capture and risk mitigation for each actor to maintain their engagement and commitments during circular processes (e.g., design for disassembly, design for energy efficiency, material donation, and material reuse).

Such circular contractual agreements should also address CE-related complexities and uncertainties that current conventional contract formats might fail to recognise. The CE-adapted contract should clarify terms of benefits, responsibilities, and risks of the involved partners in joint circular projects. This issue of misusing the traditional contract formats for circular building projects is also briefly discussed in the study of Rios et al. (2015), which suggested to include comprehensive contractual terms concerning deconstruction and material reuse in each specific construction project. Additionally, the Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) can also be the useful tools to identify and measure the risk factors concerning balance of costs, material quality and remaining lifespan.

5.3. The driving forces of new and indirect actors

In line with several previous studies such as one of Henry et al. (2020), we explain the pioneering and orchestrating roles of new actors in the CE transition of the built environment. In addition to the keystone actors such as developers and municipalities, new actors act as a driving force to drive the socio-technical trajectory shift in the circular building ecosystem. The keystone actors have increasingly collaborated with startups to co-create values and innovations for circular construction projects. Partnering with tech-leading startups gives contractors advantages to elevate digital technology competencies, reduce project costs, and increase circular possibilities.

The emergence of startups such as digital marketplace providers, physical warehouse providers, technology providers (e.g., blockchain and digital platforms), and data-driven energy optimisation service providers also addresses the need for supply-demand information. Furthermore, these actors provide digital market platforms to enhance accessibility and reduce discrepancies in the reusable material information flow. These circular startups provide access and data analytics to manage material streams and analyse supply-demand dynamics. Table 7 gives examples of Norwegian startups contributing to the circular built environment.

In addition to startups, CE consultant organisations founded by private-public partnerships also drive pilot projects and innovations in the sector. These new CE consultants collaborate and advise developers on circular building projects. These actors also codify and diffuse the 'know-how' in the sector by developing criteria and guidance and elevating the circular capacities of their partners. The success of circular building projects led by these CE consultants is crucial to demonstrating the feasibility of material reuse in practice.

Furthermore, indirect actors, such as banks issuing green loans and building tenants, can also impact the CE. As mentioned by the European Commission (2020a), p. 11), the green loan issuers "can promote the aggregation of small projects, offer favourable conditions for complex projects with long payback times and unite the various actors involved in taking buildings renovation".

Additionally, green financing can provide direct actors such as developers with a longer paying time and lower interest rates for circular projects so that the involved actors would be more incentivised to implement circular activities. The CE and energy efficiency approaches should also be shifted to more user-centric, where the role of building

Table 7
Examples of new actors in the slowing and closing the loop principles.

Categories	Examples (in Norway)	Products/ services
Digital marketplace platform	Rehub	Material database and digital marketplace for reused materials and components.
Physical market bank	Ombygg, SIRKEN	Intermediate storage warehouse of reused or surplus building materials.
CE consultancy, report, and planning	Resiqel, Sirkulær Ressurssentral	Building reports/ consultancy for EoL buildings and reuse strategies.
Digital tool for CE	Loopfront	Digital tool for circular resource planning, reporting, and product data.
Public-private organisation	FutureBuilt	Guidelines and criteria to realise CE strategies in new projects. Market dialogues and training for the actors.

users and tenants is more central in the decision-making and use process.

6. Conclusion

Our study adopted the inductive, exploratory multiple case-study approach with primary interviews and secondary data to examine the circular building ecosystems. The multiple case-study method reveals the heterogeneity and diversity in characteristics and roles of the actors in the circular ecosystem. For example, small developers and municipalities tend to have less circular ambition or negotiation power for CE goals with contractors than their larger counterparts.

This study illustrates the complex, intricate dynamics of actor collaborations in the built environment's circular ecosystems where the actors tend to be grouped by the same value proposition (i.e., construction project-oriented and locally oriented). The actor collaborations along the CE processes appear non-linear and multidimensional (top-down vertically, bottom-up vertically, and horizontally). Our study also shows how different circular ecosystems interact on the regime level and the actor interactions within the ecosystem at the niche level. Keystone actors such as municipalities and developers are essential in knowledge diffusion and innovation development within and between circular ecosystems. Furthermore, the new CE processes have led to the significant emergence of new technology providers, material banks, and new CE actors acting as the ecosystem's driving force.

Comparing with linear processes, we have also mapped the actor networks by the CE principles of narrowing, slowing, and closing the loop. Collaboration in this sector involves not only opportunities but also conflicts, scepticism, confusion, and refusion. This study also unveils risks and challenges for multi-actor collaborations during circular activities. Based on these new insights, we suggest policy implications to reinforce collaboration dynamics and CE practices in the built environment.

6.1. Policy implications

The policy approach for the circular built environment tends to be top-down from policymakers to practitioners (e.g., developers and contractors). For example, in Norway, the national authorities provide guidelines and regulations from the national level but also leave room for local authorities to make decentralised decisions for their regions. This policy approach could minimise potential risks of irrelevant circular policies and local geographical characteristics (e.g., municipal negotiation powers and development goals).

The policy review in section 2.3 shows that the European Commission has enacted diverse policy instruments, including three main categories of regulatory frameworks, monetary incentives and soft instruments. This has shown, to a certain extent, the effects of the CE acceleration of the European construction industry. A policy-mix approach combining regulatory, monetary, and soft instruments should be well-suited for the circular construction transition.

First, the sector still requires more detailed and actionable regulatory frameworks to guide actors in circular strategies. On the one hand, the regulation for CE adoption should be tightened. Mandatory material reuse percentages are needed for new buildings. New construction projects should incorporate a certain percentage of design for disassembly, repair, energy efficiency, and material reuse. These circular ambitions can be set with achievable goals, starting with a lower rate and gradually increasing over the years.

On the other hand, the regulation of documentation requirements should be simplified to reduce the barriers to material reuse. The Norwegian government has enacted measures to address this challenge by providing municipalities with an increased possibility of assessing the building condition and granting exemptions from technical requirements related to conversion, rehabilitation, and repurposing of building utility.

Second, both incentive and disincentive monetary policies are equally significant. On the one hand, to incentivise the actors, costs of reused materials such as plastic should be exempted from VAT tax and be set at affordable prices to compensate for risks of reused material quality. This approach can compensate for the risks for the involved actors, incentivise more participating actors, and foster new market segments (e.g., private users). On the other hand, to reduce unsustainable activities, higher disposal fees should be enacted to reinforce disassembly activities, replacing demolition and waste deposit habits. Such stricter requirements for deconstruction and waste sorting may improve the supply sources for the material reuse markets and higher taxation schemes on primary materials to reinforce the utility of reclaimed materials.

From the actor's insights, using regulatory and monetary instruments simultaneously is crucial to impose circular actions and create the material reuse market. In addition, soft instruments should also be supplemented. More robust stimulating policies for data-driven technology, artificial intelligence, robotic technology, and a streamed national material databank are needed to increase the possibility and efficiency of material scanning, identifying, evaluating, and automatically disassembling buildings. Finally, the policy approach to match demand and supply in the private builder market, such as the One-Stop-Shop scheme, should also continue to be implemented at a larger scale. Table 8 displays our suggested policy instruments in the main stages of circular buildings.

6.2. Managerial implications

The adaptation to CE might increase the complexity of projects. The CE strategies of narrowing, slowing and closing the loop need to be addressed early enough in the concept development and design phases for enough time for decision-making. In other projects dealing with high complexity (e.g., Zero Emission Neighborhoods), the goals and priorities of the project need to be decided early. Each of the CE strategies influences the design and costs of the project. Creating near-zero emission buildings (nZEB) to narrow the loop involves a complex coordination and trade-off process.

Reusing building elements in new or refurbished buildings is possible, but adapting material reuse to design would lead to a significant difference in cost. These complex processes are typically reciprocal, where one solution may typically affect other solutions, making the

Table 8
Recommended policy instruments by three main stages.

Designing and planning	Operating	End-of-life management
• Obligatory percentages on design for disassembly • Obligatory percentage of material reuse in new buildings • Impose higher taxes for new materials in new buildings. • Impose higher fees for building waste using landfill	• Subsidy for rehabilitation and renovation instead of new building.	• Obligatory percentage of material reuse in old buildings • Simplify standards for reused materials. • Provide subsidised tax on reused materials and circular building properties. • Impose material return/ deposit scheme. • Grant research in advanced technologies (AI robotics and machine learning) for automated material mapping and disassembly. • Build a national material stream database for material mapping. • Reinforce One-Stop-Shop approach to match private demand and supply market.

design process undecided. Therefore, clear goals and priorities will assist managers in decision-making.

Different collaboration models such as Lean, Building Information Modeling (BIM) or Virtual Design and Construction (VDC) are also recommended. Typical for these new collaboration models is the need for tighter integration of all actors in the value chain and a front-end focus of the circular project. This requires effective leadership to ensure that the overall project goals are met while allowing enough flexibility to maximise the value of the project for the users and owners.

6.3. Limitation and future research agenda

This study is conducted within the Norwegian context through nineteen qualitative interview cases. With unique characteristics of the Norwegian context, such as high labour and coordination costs as the significant barriers, the Norwegian context may lead to heterogeneities in findings compared to the contexts of other countries. Despite that, with its considerable progression in the CE transition, Norway still serves as an illustrative example of how a CE in construction can be enabled in high-cost countries.

This paper opens a future research agenda within the CE of the built environment. First, most studies focus on the technical solutions for material reuse. However, it still lacks economic models related to risk sharing, which is a decisive factor driving the market feasibility of the material reuse model. Exploring risks associated with circular building projects remains significantly limited in the literature. This research and business gap calls for a more comprehensive assessment and research on risk-sharing models and circular contractual procurements.

Second, given that circular startups in the built environment need a market upscaling solution for material reuse models, more quantitative data and research are helpful in creating a comprehensive understanding of the economic impacts of each material type. Cost analysis should be combined with other data, such as sustainability and environmental impact, through LCA/ LCCA models.

Third, most literature concerns direct partners in circular building processes but overlooks other supporting indirect actors, such as financial institutions, partners from different industries, or consumers. This gap calls for further research to explore the topics of CE financing and the higher involvement of private builders and building tenants in the circular building ecosystem.

CRediT authorship contribution statement

Phuc Huynh Evertsen: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Vegard Knotten:** Writing – review & editing.

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Appendix A. Supplementary data

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