Journal of Cleaner Production 450 (2024) 141753

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Achieving a circular economy through the effective reuse of construction products: A case study of a residential building

Alessia Bellini [a,*], Bjørn Andersen [a], Nora Johanne Klungseth [a], Allen Tadayon [b]

[a] *Norwegian University of Science and Technology NTNU, Department of Mechanical and Industrial Engineering, Richard Birkelands vei 2B, 7491, Trondheim, Norway*
[b] *OsloMet, Pilestredet 35, 0166, Oslo, Norway*

ARTICLE INFO

Handling Editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Circular construction
Circular economy
Reuse
Built environment
Data management

ABSTRACT

The building and construction industry is characterized by high consumption of raw materials, waste generation, and significant energy-related greenhouse gas emissions. A substantial change in the way this sector operates is necessary to reduce its strong negative impact on the environment. In this context, the implementation of circular strategies is critical to achieving sustainable development. Reusing construction products derived from obsolete buildings at their end of life is increasingly being investigated as a strategy to achieve circularity. Despite growing interest, both in the literature and in the industry, several challenges hinder the large-scale adoption of circular reuse. The purpose of this study is to contribute to the efficient implementation of reuse in practice. The focus is on data and information that can support the reusability assessment of construction products. The findings are obtained through a case study comprising a building project in Bergen, Norway. First, the study assesses which material properties and information are available in the project, leading to the definition of eight information-driven evaluation criteria and a three-step process for reuse. The three-step process encompasses the following: (1) collecting information, (2) information-driven evaluations, and (3) planning for reuse. Each criterion is then shown in a reusability matrix, emphasizing an information-driven approach to reuse that has the potential to be extended beyond the context of the case study. Considerations for improving data management in a circular reuse process are discussed. This study provides an innovative method that may lead to a circular economy and sustainable development in the future.

1. Introduction

A circular economy (CE) can support the shift from a linear consumption system to closed material loops, with the aim of achieving both economic growth and sustainable development (Ellen MacArthur Foundation, 2013; Geissdoerfer et al., 2017; Korhonen et al., 2018). However, the global economy in 2023 has been assessed as only 7.2 % circular, with the linear economy model continuing to prevail (Circle Economy, 2023). There is a growing need to introduce circular and regenerative approaches into our economic model (Circle Economy, 2023). In fact, the implementation of a CE could alleviate pressure on the environment by promoting the more efficient use of natural resources, reducing the exploitation of raw materials, and minimizing waste, thus limiting the carbon footprint produced (EU Commission, 2020). The building industry is especially characterized by the high consumption of resources and high rates of energy-related greenhouse gas (GHG) emissions (EU Commission, 2020), and most building elements are still not designed according to the principles of a CE (Benachio et al., 2020). While some European countries, such as the Netherlands, Italy, Slovenia, and the UK, demonstrate high rates of construction and demolition waste (C&DW) recovery and recycling and are the taking initiative to avoid landfilling (Eurostat Statistical Office of the European Union, 2020), conventional demolition is still a common practice. The development of CE in the building industry has been almost exclusively driven by practitioners (Korhonen et al., 2018), and in recent years, the focus has been on recycling and waste prevention (da Rocha and Sattler, 2009; Norouzi et al., 2021; Harala et al., 2023). Maximizing the reuse of secondary construction products is often suggested as a strategy via which to enhance circularity (Kirchherr et al., 2017; Circle Economy, 2023); however, it is estimated that only about 1% of deconstructed construction products and components are reused today (Byers et al., 2023). In a CE, reuse entails components being used again, as a whole,

* Corresponding author.
E-mail addresses: alessia.bellini@ntnu.no (A. Bellini), bjorn.andersen@ntnu.no (B. Andersen), nora.klungseth@ntnu.no (N.J. Klungseth), allentad@oslomet.no (A. Tadayon).

https://doi.org/10.1016/j.jclepro.2024.141753
Received 12 June 2023; Received in revised form 7 February 2024; Accepted 11 March 2024
Available online 16 March 2024

for their original purpose (Harala et al., 2023). The aim is to retain their value, prolong their lifespans, and reduce waste and the exploitation of new resources (Benachio et al., 2020; Arora et al., 2021). Moreover, recovering C&D waste can lower GHG emissions and energy consumption (Diyamandoglu and Fortuna, 2015). The embodied energy of materials corresponds to a considerable amount of the total energy consumed during the building life cycle; therefore, the energy savings accrued by reusing construction products can also be significant (da Rocha and Sattler, 2009). Thus, because the current building stock can serve as source of reusable materials for present and future buildings, the subject of reuse has been investigated by several authors, including Benachio et al. (2020), Honic et al. (2021) and Çetin et al. (2023). Moreover, Kozminska (2019) outlined the process for reusing construction products from an organizational perspective, Nußholz et al. (2019) investigated the carbon-saving potential of secondary products and waste materials, and Harala et al. (2023) explored the changes within the industrial ecosystem that can yield benefits via reuse. Other researchers, such as Mêda et al. (2020), Çetin et al. (2021), and Berglund-Brown et al. (2022), analyzed the role of digitalized information and data management in CE and reuse. Similarly, Byers et al. (2023) investigated how to acquire sufficient information for the reuse of building materials, also considering the potential of digital technologies in this regard. Digital technologies in connection with CE principles can enhance the potential to achieve a sustainable built environment (De Wolf et al., 2024). Thus, data management standards and digital technologies are crucial to enabling sustainable and circular transformation in the built environment (Klungseth et al., 2023).

Despite growing awareness and interest, CE is slowly being adopted in the building industry (Kirchherr et al., 2017; Byers et al., 2023), and research shows a lack of understanding of how to employ circular strategies in practices (Benachio et al., 2020). In this context, there is also a need to improve the implementation of reuse as a circular strategy because its widespread application still faces several challenges (Harala et al., 2023). This study contributes to improving the awareness of practical CE implementation, with a focus on the reuse of construction products as a circular strategy. The purpose is to enhance the efficiency of the reuse process through improved data management, as examined in the context of the Nøstebukten Brygge case study. The Nøstebukten Brygge project entails the reuse of reclaimed construction products from an obsolete building at the end of its life. This building, which is in Bergen, Norway, was formerly used as the headquarters for the broadcaster TV2, one of the largest media companies in Norway, and it will be demolished to make way for a new residential complex. The Nøstebukten Brygge project, in collaboration with Proptech Innovation, aspires to improve CE implementation in the Norwegian building industry, mainly through the reuse of construction products, despite other circular strategies being implemented. This case study was selected because it is currently one of the largest projects in Norway that requires the reuse of construction products as a strategy via which to achieve CE. It also involves leading actors in the building industry. This study contributes to the relatively narrow body of knowledge that investigates the reuse of construction products in connection with CE. The project participants were concerned about finding an effective way to evaluate which construction products could have been reused from the obsolete building. In general, information and data about existing construction products are often missing or incomplete, which makes it difficult to assess their reusability. Therefore, the research question for this study is as follows:

RQ: Which information-driven evaluations should be conducted in the early phase of new construction projects to assess which elements of obsolete or existing buildings could be reused or repurposed in new projects?

To answer the research question, we will follow three steps:

Step 1. Assess which information and properties about construction products are available in the project.
Step 2. Define a series of criteria that can be used to evaluate the reusability of a construction product.
Step 3. Suggest how to improve data management in a circular reuse process.

The findings are obtained through a mixed-methods research design and comprise both reporting on the case study and the design of a new framework. The framework consists of a three-step process for the reuse of construction products (presented in Section 4) and a reusability matrix (presented in Section 5). These can be applied outside the context of the case study and contribute to improving the efficiency of the reuse process from a managerial perspective, reinforcing the central role of information in the successful implementation of a CE. Moreover, the matrix can be used to estimate the reusability potential of construction products based on eight information-driven evaluation criteria. These criteria are defined by the authors through a process of logical intuiting and considering existing standards and regulations.

Considering the complexity of the context, it was important to define certain limitations on the scope of this study to ensure the relevance of the results. First, this study considered reuse as a strategy via which to achieve CE within the specific context of the residential Nøstebukten Brygge project in Norway. We only focused on the reuse process during the early phase, beginning with the project owner's expressed requirements. Because of the holistic nature of the subject, in the analysis, we adopted a project management perspective, considering the environmental, economic, and organizational dimensions in the discussion. That said, it is beyond the scope of this research to examine technical details connected with the architectural or engineering aspects of the project. This study is an attempt to delineate a standardized and efficient process for the reuse of building products, and further research is needed for a more comprehensive analysis of CE implementation in the building industry.

The remainder of this paper is organized as follows: Section 2 presents the theoretical background and state of the art drawn from the literature. Section 3 detailed the research method and case study. Findings are reported in Section 4, followed by a comprehensive discussion in Section 5. The paper concludes with Section 6 offering a summary and exploring possibilities for future research.

2. Theoretical background

This section presents the subject of CE in the context of the built environment, with a focus on the reuse strategy. In particular, we underline the role of digitalization and data management for the CE and highlight the gaps in the literature.

2.1. Circular reuse and repurposing in construction: concepts and importance

Despite the growing awareness of CE in the building industry, some authors have pointed out that circular processes are not yet widely implemented, perhaps because a common definition is still lacking (Kirchherr et al., 2017; Kirchherr et al., 2023; Figge et al., 2023) or there is a lack of understanding of how to implement circular strategies in practice (Benachio et al., 2020; Charef and Emmitt, 2021). By minimizing resource waste and emissions, CE is often linked to sustainable development and ensures that resources are available for current and future generations (De Wolf et al., 2024). In the built environment, a CE can be achieved through several strategies, namely adaptability and design for disassembly, lifespan extension, and the reuse and repurposing of construction products (Cheshire, 2019). Different strategies can have different impacts on sustainability. The strategy of retaining value from reusing reclaimed end-of-life components can significantly contribute to decreasing resource consumption and GHG emissions (Diyamandoglu and Fortuna, 2015), but it requires an innovative way of managing resources and a systemic approach to value chain integration

(Pomponi and Moncaster, 2017; Heisel and Rau-Oberhuber, 2020; Munaro and Tavares, 2021; Knoth et al., 2022). Reuse is not a new concept (da Rocha and Sattler, 2009; Diyamandoglu and Fortuna, 2015) and implies that the construction products are salvaged and reintroduced in another building, thus maintaining the original function, avoiding material downcycling (Benachio et al., 2020; Çetin et al., 2021; Zatta and Condotta, 2023). On the other hand, repurposing suggests that products are reutilized with a different function, often implying a downcycling pattern (Kirchherr et al., 2017; Byers et al., 2023). During the last few years, an increasing number of studies, such as Norouzi et al. (2021) and Zatta and Condotta (2023), have investigated reuse as a circular strategy. However, how companies can increase circularity through reuse strategy and, more specifically, how the supply chain can be organized to enable reuse remains unclear (Harala et al., 2023). In this context, Harala et al. (2023) investigated which changes in the industrial ecosystem can contribute to creating value from reuse and how the different actors need to collaborate to promote circularity. The authors refer to an ecosystem as an "entity of complementary actors taking varying roles linked through interdependencies" and call for systemic action to generate economic and environmental benefits in a CE (Harala et al., 2023). Other authors, such as Diyamandoglu and Fortuna (2015), have investigated the impact of waste management and reuse on GHG emissions and energy savings in a residential project. Similarly, Nußholz et al. (2019) focused on business model innovation and investigated the carbon savings potential of reuse. Muñoz et al. (2023) explored the methodologies that are currently used to assess the environmental impacts of CE and concluded that a common approach does not yet exist.

Barriers to and opportunities for implementing reuse in practice have been highlighted by several authors. In 2009, da Rocha and Sattler identified the major barriers and opportunities regarding the reuse of building components during the demolition phase. The costs associated with dismantling a building, inconsistencies of quality, client perceptions, regulations, and information flow problems were identified by the authors as factors affecting reuse (da Rocha and Sattler, 2009). In more recent times, Munaro and Tavares (2021) found that a lack of awareness and holistic thinking, coupled with insufficient information and the fragmentation of the value chain, can hinder the adoption of CE strategies. Knoth et al. (2022), Nordby (2019), and Sandberg and Kvellheim (2021) analyzed the technical, legislative, environmental, and market barriers to reusing materials in Norway and concluded that the lack of economic incentives and requirements could limit the reuse of construction products on a larger scale.

2.2. *The role of digitalization, technology, and data management in circular construction*

The success of the reuse strategy in a CE largely hinges on the availability of information about construction products, while many existing buildings are poorly documented, often resulting in incomplete or hard-to-assess information (Munaro and Tavares, 2021; Bellini and Bang, 2022; Berglund-Brown et al., 2022; Çetin et al., 2023; Byers et al., 2023). As underlined by Berglund-Brown et al. (2022), there is a need to improve the accessibility of product data among construction firms by integrating circular information into a firm's business strategy. Efficient data traceability and the adoption of digital technologies for collecting construction product properties are critical to circular constructions (Mêda et al., 2021). Byers et al. (2023) investigated which digital technologies and tools are used for data acquisition for potential material reuse. These include, for example, data sheets' documentation, modeling systems, artificial intelligence (AI), spatial data acquisition techniques, and the internet of things (IoT). Generally, a growing body of research investigated how digital technologies, such as building information modeling (BIM), IoT, or AI, could support the transition to a CE (Çetin et al., 2021; Charef and Emmitt, 2021; Chiaroni et al., 2021; Chauhan et al., 2022; De Wolf et al., 2024). However, according to Byers et al. (2023), there is a gap between what is explored in research and the practical adoption of digital technologies in the building and construction industry Information about building elements can be collected and stored in a material passport or integrated into BIM software. BIM combines geometrical and alphanumeric information about a built asset and is commonly used for data exchange on medium and large design projects (Tomczak et al., 2022). Charef and Emmitt (2021) explored BIM uses that can potentially facilitate the adoption of CE, including developing a material passport and enhancing processes for circularity assessment and material recovery. Akanbi et al. (2018) presented a BIM-based tool that can be used to assess the reusability potential of building elements during the design phase. Similarly, Arora et al. (2019) emphasized that a lack of information is a major barrier to reuse and proposed a method for estimating the availability of reclaimed construction products at the urban level. Other authors have focused on the concept of a Material Passport (MP), as one of the main enablers of a CE in the built environment (Çetin et al., 2021; Honic et al., 2024). An MP is a tool that contains a set of information about a specific product; for example, its physical properties, chemical and biological composition, emissions, certification requirements, design and production, logistics and traceability, and instructions for disassembly and recycling (Hoosain et al., 2021; Munaro and Tavares, 2021). Munaro and Tavares (2021) assessed the importance of structured information for CE and explored state-of-the-art MPs, with the goal of raising awareness and expanding their implementation in the industry. Similarly, Mulhall et al. (2022) presented an MP for circularity and found that standardized data about products and components were not broadly available in the industry. Çetin et al. (2023) focused on the data requirements of various MP users and analyzed the extent to which such data are available for existing buildings. It emerged that several critical data about buildings and products, such as the composition of materials, condition assessment, and reuse and recycling potential, are often difficult to obtain (Çetin et al., 2023). Moreover, Heisel and Rau-Oberhuber (2020) described how to generate an MP for an existing building using a digital MP platform. Furthermore, other related concepts, such as data templates, digital product passports (DPPs), product circularity data sheets, building renovation passports, and digital building logbooks, can support the digitization of product information for a CE (Mêda et al., 2021; Honic et al., 2024). Regardless of the application, it is important that the data stored in data repositories are in an accessible format, are compatible with various software programs, and can be integrated into BIM (Munaro and Tavares, 2021). Interoperable software is based on international BIM standards, such as Industry Foundation Classes (IFC), which allow open data exchange (Honic et al., 2021; Tomczak et al., 2022). Kovacic et al. (2020) presented a conceptual framework for a digital platform that could allow continuous data and information flow. The authors emphasized that for the digital platform to be integrated into a BIM model or MP, the product data and properties must be structured based on a standard product template to ensure accessibility and data exchange along the value chain (Kovacic et al., 2020). Sandberg and Kvellheim (2021) suggested creating a product data template for reuse based on an open format, which could facilitate the exchange of data between manufacturers and end-users throughout the entire lifecycle. One way to standardize product data is via a product data template (PDT), which was introduced and defined in international standard ISO 23386, which was published in 2020, although it did not focus on CE. However, the most used methods for managing information requirements for BIM today are still text-based documents that are compiled into PDF files via spreadsheets (XLS format; Tomczak et al., 2022).

From a more managerial perspective, Kozminska (2019) analyzed the design process for the reuse of building elements to identify both challenges and success factors. Reuse strategies are typically adopted when the demolition of a building is unavoidable. In an easy scenario, the reclaimed products are reused directly from the obsolete building at the end of its life without needing to be repaired, re-certified, or customized (Sandberg and Kvellheim, 2021). Often, an evaluation should be made *in situ* during the deconstruction phase to assess whether the building elements need to be repaired and whether it is reasonable to reuse these materials from an economic perspective (Cai and Waldmann, 2019). Therefore, the reuse process requires practitioners to possess adequate knowledge and expertise with which to identify the sources of reused materials, ensure their availability, and identify new ways of reusing them (Kozminska, 2019; Arora et al., 2021). Focusing on the Norwegian context, Sandberg and Kvellheim (2021) reported that an increasing number of project owners, both public and private, have begun to require the reuse of construction products in their projects. One issue that emerges in their report is the importance of involving architects, contractors, and other actors in an early project phase to exploit the potential for reuse (Sandberg and Kvellheim, 2021). An effective reuse process entails a systemic approach involving several stakeholders in an interdisciplinary collaboration, as well as managing product data in a centralized manner (Debacker et al., 2017; Kozminska, 2019; Berglund-Brown et al., 2022). However, only a few studies have addressed the subject of CE and the reuse of building elements in the context of data management from a managerial or strategic perspective. The study by Kozminska (2019) is a reference for the design process for the reuse of building elements and highlights the need for further research on digital data management. Finally, Berglund-Brown et al. (2022) analyzed the characteristics of circular information flow integrated with business strategy. This study contributes to filling the gap in the extant literature by showing, through the analysis of a case study, how the reuse process is conducted in the Nøstebukten Brygge project, and it highlights the impact of information-driven evaluations on circular construction.

3. Research method

3.1. Research design

The purpose of this study was to improve the efficiency of the reuse process through data management. This study follows a mixed-method research design, with data being collected through interviews, a workshop, and observations. These data were analyzed using both qualitative and quantitative parameters (Creswell and Clark, 2017). The Nøstebukten Brygge project, which required the reuse of construction products to achieve CE, was selected as the target case for this research project. The study adhered to the methodological recommendations of Bell et al. (2015) and Yin (2018) for the interviews and case study, respectively, while the theoretical background provided a conceptual grounding for the study and supported the interpretation of the data (Creswell, 2009; Savin-Baden and Major, 2013). Fig. 1 illustrates the research process and design for this study.

3.2. Case study description

The Nøstebukten Brygge building in Bergen, Norway, was originally built in 1914, and it had an industrial function. In the 1980s, the building was renovated and used as the headquarters for one of the largest broadcast stations in Norway, TV2, assuming iconic status (see Fig. 2). However, due to the need for deep renovation and modernization, the building has remained unused for the last few years. Following a thorough series of qualitative and structural analyses, the existing building was deemed non-compliant and unsuitable for rehabilitation, given the current technical standards and requirements. Consequently, the building owners, OBOS and EGD Properties, have opted to dismantle the existing building and start the construction of a new residential complex on the same site. The project owners have required that a significant portion of the reclaimed construction materials from the obsolete existing building be reused in the new project, which in aligned with a circular economy strategy. Additionally, the project must meet the requirements for the BREEAM-NOR accreditation. The project is currently in the design phase, and construction is planned to commence in 2024. Considering the extent of the project, it is necessary to limit the

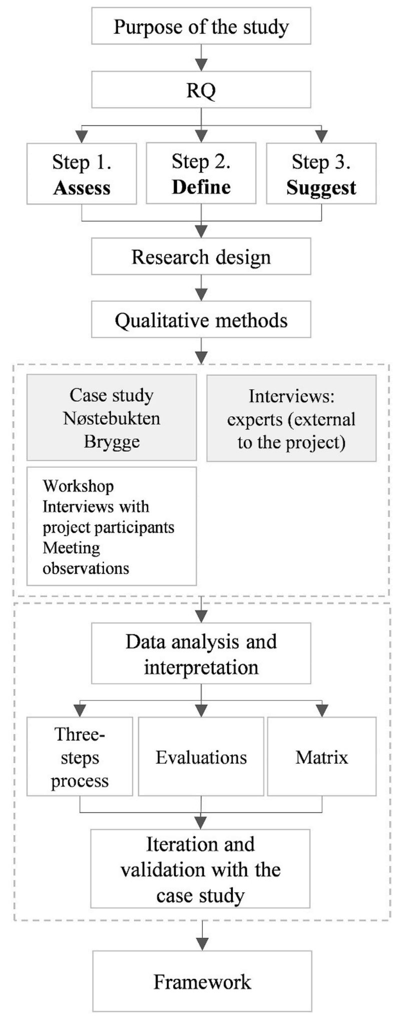


Fig. 1. Research design and process.

Fig. 2. The existing building in Nøstebukten Brygge, Bergen.

scope of this study. For example, even though the two areas are strongly connected, this research will mainly assess circular requirements and will not directly consider the environmental criteria and assessment of the project. Although some technical considerations are necessary to understand the findings, the evaluations performed in this study assume a project management perspective. Finally, the context and specific characteristics of this project should be considered when analyzing the findings.

3.3. Data collection

This study employed the following methods for data collection: eight semi-structured interviews with project participants, a workshop, meetings observation, and 18 semi-structured interviews with experts who were not participating in the project. The semi-structured interview method was particularly effective because it allowed the interviewees to elaborate beyond predefined questions and ultimately gave way to follow-up questions (Bell et al., 2015). The 18 interviews with industry experts were conducted first (November 2021 and February 2022), originally in the context of a previous study published in November 2022 by Bellini and Bang (2022). The data that were not included in the previous study were contextualized in the case study of Nøstebukten Brygge and provided a valuable assessment of circular economy and data management, thereby improving the quality of the results. The project was identified as an interesting case in January 2022, and the collaboration with OBOS and EGD Properties began in February 2022. After a period of preliminary discussion and research definition, a workshop was conducted in Bergen, Norway, in September 2022. The eight interviews with the project participants were conducted from November to December 2022.

3.3.1. Workshop with project participants

The scope of the workshop was to map the main steps in and information-driven evaluations of the reuse process for the Nøstebukten Brygge project. Seven people participated in the workshop, including the project owner and contractors (see Table 1). The main author led the workshop using the Miro software program and maintained a neutral position, without influencing the participants' meanings and answers. The workshop lasted approximately 3 h, and the discussion was recorded to ensure reliability and avoid any misunderstandings during the analysis of the results. The outcome was a draft of the reuse process based on the contextual scenario of the project. For increased quality assurance, the draft was sent to the participants and validated and enriched with the data collected through interviews and observations.

3.3.2. Eight semi-structured interviews with project participants

Eight semi-structured interviews were conducted with representatives from the project, including the owner, contractors, architects, and interior designers (as listed in Table 2). Six of the eight interviewees participated in the workshop. None of the project participants had previous experience working directly with CE in a building project. One interviewee had studied CE at the university level, while others had previously been engaged in circular projects. All participants had a strong focus on sustainability and were motivated to introduce a circular reuse process in the project. Each interview lasted between 45 and 60 min and was conducted online using Microsoft Teams due to the geographical distance between the interviewer and interviewees. The interviews were conducted by the same author. The interview guide was sent to the interviewees prior to the interviews because it was considered important to give them an opportunity to evaluate their capacity to contribute to the subject, as well as to ensure that their expectations were aligned with the research needs. The interviews were recorded, and the transcriptions were sent to the interviewees for quality assurance before analyzing the data further. The interviews were conducted in Norwegian and then translated into English by the authors to ensure accuracy and avoid the misinterpretation of the data. The coding process was performed iteratively in parallel with the interviews, as recommended by Bell et al. (2015), and while considering the findings obtained from the workshops and observations.

3.3.3. Meeting observation

The main author participated as an observer in two additional project meetings conducted after the workshop. Table 3 provides a description of these meetings. The aim of doing so was to supplement the information collected during the interviews and follow up on the development of the project and the reuse process. The researcher participated in these meetings as a "complete observer," meaning that they did not interfere with the discussion but, rather, simply observed and took notes (Creswell and Báez, 2016).

3.3.4. Eighteen semi-structured interviews with experts

The respondents who participated in the 18 semi-structured interviews, which were conducted before starting the project, had significant experience with and knowledge of CE and digitalization. They were chosen because of their involvement in pilot projects, workshops, and networks addressing CE and material reuse. To ensure valid and

Table 1
Overview of the workshop participants.

	Role	Affiliation	Years of experience
Participant 1	Project manager & civil engineer	Contractor	20
Participant 2	Project manager	Project owner	10
Participant 3	Project engineer	Contractor	2
Participant 4	Energy & environment specialist	Contractor	10
Participant 5	BREEAM & environmental specialist	Contractor	10
Participant 6	Project engineer	Contractor	10
Participant 7	Customer contact management	Project owner	5

Table 2
Overview of interviewees (8) among the project participants.

	Role	Affiliation	Years of experience	Workshop participant
Interviewee 1	Project manager & civil engineer	Contractor	20	Yes
Interviewee 2	Project director	Project owner	10	Yes
Interviewee 3	Customer contact manager	Project owner	5	Yes
Interviewee 4	Interior designer	Interior designer	20	No
Interviewee 5	BREEAM & environmental specialist	Contractor	10	Yes
Interviewee 6	Project engineer	Contractor	2	Yes
Interviewee 7	Project manager	Project owner	10	Yes
Interviewee 8	Architect lead	Architect	5	No

Table 3
Information about meeting observation.

			Participants	Meeting Scope
Meeting 1.	Oct.22	Hybrid	Project owner, contractor, architect, and interior designer.	Discuss which products could be reused in the new project./Evaluate possibilities and potential functions.
Meeting 2.	Mar.23	Hybrid	Project owner, contractor, and architect.	Exchange information with architects for design and planning./Consider how to reuse the wood structure and bricks./Explore opportunities for trading other products on external marketplaces or recycling./Discuss possibilities to include reclaimed materials in the private areas (apartments)./Discuss how to involve the suppliers and manufacturers in the process.

Table 4
Number of respondents by position in the value chain.

Role	Number of respondents
Manufacturer	1
Project owner	3
Architect	1
Research institute and university	2
Not-for-profit organization & network	2
Software provider	3
Engineering & sustainability consultant	4
Contractor	2

relevant findings, a broad sample of interviewees was chosen to include various roles in the value chain, from manufacturers to contractors (Table 4). All interviewees had more than 5 years of experience working within the building and construction industry, either in major and well-known organizations in Norway or in software development companies developing solutions and platforms for a circular economy. Each interview was conducted online due to the COVID-19 regulations in Norway at that time. To ensure data quality, the interviews were recorded, and the respondents received, read, and approved the transcription. The interviews were conducted in Norwegian by the same author and subsequently translated into English to ensure accuracy and avoid the misinterpretation of the information. This set of data enriched the findings and increased their validity because the participants in the Nøstebukten Brygge project did not have direct experience working with circular reuse in a building project.

3.4. Data analysis

The aim of data analysis is to provide a sense of direction to the findings and reach valuable conclusions (Yin, 2018). The data collected from the case study and interviews were analyzed through an inductive and iterative process (Gioia et al., 2013; Savin-Baden and Major, 2013; Yin, 2018), adopting thematic analysis as the method for obtaining valuable findings (Braun and Clarke, 2006; Savin-Baden and Major, 2013). Thematic analysis involves searching for patterns within the data, in the form of qualitative codes and themes (Braun and Clarke, 2006; Savin-Baden and Major, 2013). During the thematic analysis, we conducted the following steps, which were based on Braun and Clarke (2006) and Gioia et al. (2013): (i) transcribe and read the data multiple times to familiarize oneself with the concepts; (ii) generate initial codes using a systematic approach, adhering to the interviewees' terms; (iii) find similarities and unite codes into themes; (iv) review the emerging themes and generate a data structure; and (v) refine the themes, relating them to the research question and purpose. An example of data coding is illustrated in Table 5. Emergent themes and concepts were contextualized and interpreted in relation to the theoretical framework, which served as a guide in extrapolating the results (Gioia et al., 2013; Savin-Baden and Major, 2013). Finally, the authors inductively analyzed the interrelationships emerging from the concepts, themes, and theory (Gioia et al., 2013) and captured them in the findings, which are presented in Section 4.

The data specifically collected through the workshop were structured and visualized as a three-step process using Miro. Constructing a visual display can facilitate discoveries within the data (Yin, 2018). The process was then assessed and continually enriched with the data collected from interviews. The results derived from the interviews with experts from the industry were collected first and reprocessed later by the authors. The patterns observed during the workshop were coherent with the themes derived from the interviews. The results were also consistent with the concepts derived from the literature, suggesting that the findings are highly relevant.

The authors took specific steps to ensure the validity and reliability of the findings. First, following the recommendation of Creswell (2009), the authors documented the research procedures to ensure consistency and held periodical meetings to assess the process. Moreover, the authors checked the transcriptions of the interviews to avoid errors and sent them to the interviewees for quality assurance and to avoid misinterpretations. The data were collected through converging sources (interviews, workshops, and observations) and cross-checked with the theory, following a triangulation approach to ensure validity (Creswell, 2009). The study results were contextualized in terms of the specific project. Additionally, adding the data collected from experts outside the project contributed to the generalization of the findings and provided higher reliability. Finally, the study authors had different backgrounds and competences, which was important in minimizing interpretation bias.

4. Findings

The findings of this study include the three-step process for reuse and the criteria for evaluating the reusability of a construction product. A detailed description of each evaluation criterion is provided in Section 4.2, including the consideration of how these evaluations were conducted and integrated into the project for decision-making.

4.1. Three-steps process for reuse of construction products and information-driven evaluations

As shown in Fig. 3, the process for the reuse of construction products includes the following steps: (1) collecting information, (2) performing information-driven evaluations, and (3) planning for reuse. A more

Table 5
Example of data structured in codes and themes, based on methodological theory by Braun and Clarke (2006) and Gioia et al. (2013).

Transcript of text	Code	Theme
"We don't have anything else than an Excel file from the reuse mapping. This constitutes the information about existing construction products. We need to document which product we are going to select for reuse. But I am not sure if we will need a digital system"	"(…) an Excel file from the reuse mapping (…) constitutes the information about existing construction products" "(…) not sure if we need a digital system"	01. Available information for reuse 02. Use of digital technologies
"The only system we use (for reuse mapping) is an Excel-file that shows which products could potentially be reused and for which function"	"(…) Excel-file shows which products could potentially be reused and for which function (…)"	01. Available information for reuse

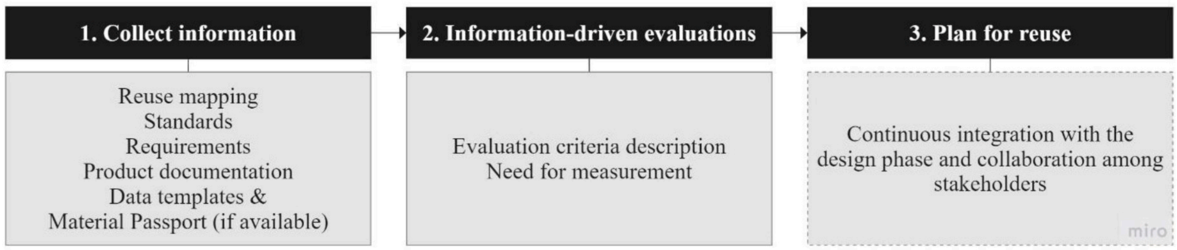


Fig. 3. Three-steps process for reuse of construction products.

detailed representation of the three-steps process is illustrated in Fig. 4.

4.1.1. *Collect information*

This step implies assessing what information about the construction products used in the project is available (Step 1). The information about the existing construction products was mainly collected through reuse mapping. In the Nøstebukten Brygge project, reuse mapping was carried out during the early design phase by engineering consultants on behalf of the project owner. The aim was to identify potential reusable products, end-of-life products to recycle, and hazardous materials to dispose of. The reuse mapping for Nøstebukten Brygge showed that several building products and materials, such as internal walls and doors, wood frames, and bricks, could be reclaimed from the obsolete building, while other construction products were more suitable for recycling because they were worn out or did not comply with modern standards. Information was also collected from other sources, such as project documentation; project requirements; technical regulations; standards, for example, NS 3451:2022; and, if extant, data templates or MPs. It was important to acquire information about structural properties (e.g., a load-bearing element), life expectancy and durability assessment, and as-built documentation. Additionally, the criteria for BREAAM-NOR accreditation were also included because this was a requirement for the project. BREEAM-NOR (Building Research Establishment Environmental Assessment Methodology) is a third-party validation and certification system for a sustainable built environment that has been adapted to the Norwegian context (Grønn Byggallianse, 2024).

Generally, data on materials' properties should be collected in a digital format and stored in a database or an MP. In the early project phase, the information flow was not automatically integrated into other digital solutions, and the project team had not yet implemented specific measures for transferring data along the value chain and through the entire asset lifecycle. Initially, information from reuse mapping was collected in an Excel file and a report, with the intention of later transferring these data into a digital database or MP. Today, several providers and organizations offer guidelines and templates, including recommendations about which properties should be considered when attempting to increase circularity. However, a standardized format has not yet been identified in the Norwegian building industry. Table 6 provides examples of data, in the form of product properties, classified through the reuse mapping for Nøstebukten Brygge project. Three construction products—internal walls, ceiling panels, and wood flooring—are chosen as examples.

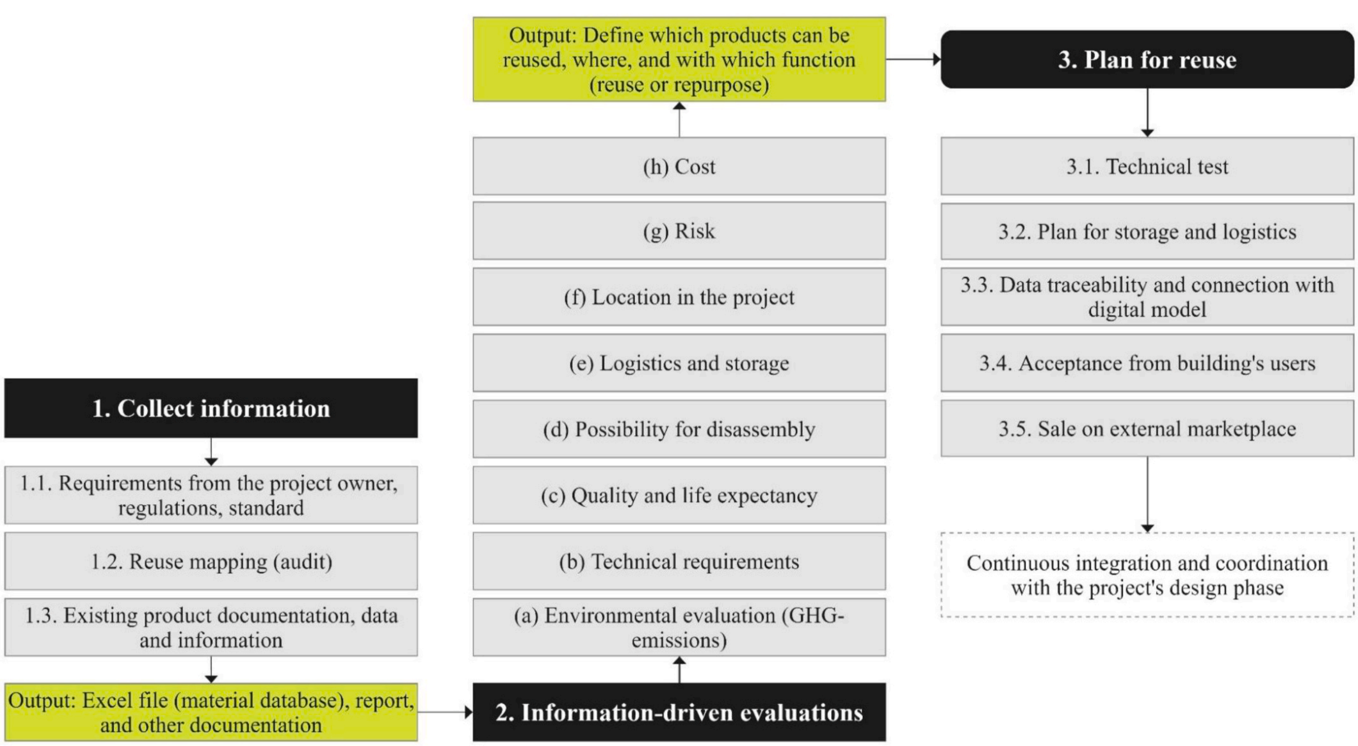
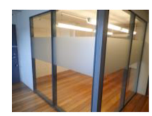


Fig. 4. A detailed representation of the three-step process for reuse of construction products for Nøstebukten Brygge project, including evaluations criteria and outputs.

Table 6
Construction products properties from reuse mapping.

Data definitions	Description	Product 1	Product 2	Product 3
Category	Classification according to NS 3451:2022	Internal walls	Roofs	Ground floor/ Upper floors
Sub-category	Classification according to NS 3451:2022	Bearing structures	Ceilings	Flooring
Material type	What type of material is the product made of.	MDF & glass	Gypsum	Gluelam wood
Situation of Material	Is the product installed in an existing building that is going to be demolished or rehabilitated, or is it placed in storage ready for collection?	In building	In building	In building
Place of placement	Is the product installed inside or outside? This can help us assess what kind of properties the product can be used for in the future.	Indoors	Indoors	Indoors
Longitude	To determine cost/benefit consequences, we need to know the product's location. This is defined as the product's longitude/latitude coordinates.	5.311996	5.311996	5.311996
Latitude	(As above)	60.393895	60.393895	60.393895
State	What condition is the material in? This determines any processing of the material to enable reuse.	Good	Unknown	Some wear
Color	Color/materiality	Various	White	Wood
CE marking	If the product is from after 2014, there is a requirement for CE marking upon sale. State (yes/no) if the material is from after 1 January 2014.	(Not specified)	(Not specified)	(Not specified)
Thickness (mm)	If the material has a size in the unit m2, it will probably also have a thickness.	(Not specified)	10	(Not specified)
Diameter (mm)	For sheaves and other round profiles, the diameter will be decisive information.	(Not specified)	600x600	(Not specified)
Quantity	Depending on which unit is selected.	(Not specified)	100	Ca.75
Unit	Measure of quantity.	(Not specified)	pcs	m^2
Documentation	Is there any documentation on the material? Standards, rapport, warranty etc.	(Not specified)	(Not specified)	(Not specified)
Date availability (DD-MMM-YYYY)	When is the construction product available for disassembly or picking up? What is the deadline for collection before it is handled as waste? When is demolition date?	(Not specified)	(Not specified)	(Not specified)
Price	Price of the material per unit. The price is only for the material, all additional services (dismantling, transport, testing and storage) must be covered by the buyer.	(Not specified)	(Not specified)	(Not specified)
Bilde	The picture should have dimensions 1:1 or 4:3.			

4.1.2. Information-driven evaluation

The criteria for information-driven evaluations from (a) to (h) are defined in Step 2. For each criterion, we indicated how these evaluations were conducted in the early design phase of the project to define which products could have been reused in the new building, where, and with which function. A lack of data about the reclaimed construction products hindered the evaluation process. At this stage, it was difficult for the project participants to measure these parameters, but the reasoning behind each evaluation was emphasized.

4.1.2.1. Environmental evaluation. Environmental evaluation includes measuring the carbon-saving potential of reusing a reclaimed construction product, compared to a new one. Carbon emissions from a building's life cycle are classified as operational or embodied impacts (Nußholz et al., 2019). Operational impact refers to the energy required for operating the building during the use phase, while embodied impact is calculated from the life cycle of each construction product, including production, refurbishment, and end-of-life (Nußholz et al., 2019). The carbon footprint can be measured as kg CO_2-eq/kg product and, at the product level, can be influenced by a range of factors, such as energy consumed during production, transportation, recyclability etc. Compliance with BREEAM-criteria should also be considered, as this is a requirement for the project. According to the interviewees, reuse prevents the production of new products, consequently, lowering the carbon footprint from manufacturing. The participants in Nøstebukten Brygge project agreed that the carbon-saving potential of a product should be included as a parameter in order to make an informed decision about reuse. However, in the early design phase, a lifecycle assessment (LCA) for the project had not yet been conducted. It was therefore not possible to determine a value to use for the environmental evaluation of the three products presented in Table 6. From the interviews, it emerged that the project participants were uncertain about how to calculate carbon emissions for the reusable products. One interviewee stated, "No one knows accurately which material or component can give higher CO_2 savings." Another project participant agreed that choosing reclaimed products in the project will contribute to lower GHG emissions but stated that this was difficult to quantify: "The footprint value for reused materials is not calculated in the analysis. The (embodied) impact is therefore minimal." The project participants agreed that reusing a larger number of products in higher quantities (e.g., reclaimed bricks) would have a stronger positive impact on carbon-saving potential. Other environmental considerations were analyzed prior to the reuse mapping to verify the presence of hazardous materials in the existing building.

4.1.2.2. Technical requirements. This criterion entails determining whether reclaimed products fulfilled the technical requirements, for example, structural, fire safety, sound isolation, and thermal conductivity requirements, considering their potential function in the new project. First, it is necessary to verify whether the technical documentation, including datasheets, as-built plans, original specifications, logbooks, archives, the declaration of performances, and CE marking, about construction products is available. Technical compliance can be tested via a visual inspection on-site or through specific tests in a laboratory to analyze mechanical or chemical performance. The project participants mentioned that it is important to involve, if possible, the manufacturers and thus obtain the original product documentation or carry out technical testing. However, one interviewee stated, "One might have the documentation for the product from the producer, but it does not mean that this is still valid today. The product might have been exposed to different conditions during the use phase and this might have compromised its technical performance." In a reuse process, the project owner may need to apply for a dispensation regarding the technical compliance of certain products. As building owners, engineering consultants, and contractors gain experience regarding which materials and components can be reused, information should be entered into a database, preferably an open-access database, so that for future projects under demolition, it can be easily determined what can be reused without having to repeat analyses that have already been performed in previous projects. Based on the available information and after a visual inspection, the project participants established that Product 1, which is presented in Table 6, did not fulfill the technical requirements and could not be reused in the new project with its original function, that of an internal glass wall. The project team will therefore consider whether Product 1 can be reused for other functions. For Products 2 and 3, which are presented in Table 6, the project participants decided that further testing was necessary to verify the compliance of the product with technical requirements for fire and thermal isolation.

4.1.2.3. Quality and life expectancy. It is necessary to evaluate the quality of reclaimed products, considering the remaining life expectancy prior to reuse. One interviewee mentioned, “It is difficult to document the quality and durability of a product in a reuse process because the contractor has to approve it and put a warranty on it.” The reuse mapping included an initial estimate of the state of construction products based on a visual inspection. In assessing this criterion, it is also necessary to consult, if available, the as-built documentation for the existing building, a record of maintenance interventions, and the product documentation. Preventive maintenance can extend the lives of construction products. Data and information collected for reclaimed products should be stored in a digital database for the project and updated over time. It was not a requirement for this project to build a dynamic digital twin, but the interviewees and experts recognized the importance of keeping track of information over time. In line with the reuse mapping and visual inspection, the project participants defined Product 1 as being in a good state, while Product 3 was showing some wear. It was not possible to determine the state of Product 2 through a visual inspection.

4.1.2.4. Possibility for disassembly. This evaluation considers if the products are composite or if can be disassembled in a sensible way. As one project participant mentioned, “It might be difficult to reuse construction products and materials because they are not designed to be disassembled.” Several interviewees believed that design for reuse and disassembly should be enhanced for a CE. Product documentation was necessary to verify this parameter. The project participants determined that Product 1 was a composite (glass and wood) and therefore could not be disassembled without compromising the quality of material. Product 2 was not a composite and could be dismantled. Product 3 could likely be dismantled, but the project participants were unsure whether this would compromise the quality of the product.

4.1.2.5. Logistic and storage. For an efficient reuse process, it is necessary to consider when a reclaimed product can be available, when this product is needed in the new project, how long it has to be stored, and where to store it. The project participants believed that logistics and storage can hinder the reuse process, and they felt that storage could impact quality, cost, and risk. One interviewee stated, “I don’t think you can avoid some sort of storage. But it is hard to precisely know when the reclaimed products are available and when you need them in the project.” Storage and logistics require appropriate planning and often imply extra costs for the project. As one project participant mentioned, “If you have to store a product for three or more years, for example, you should include this cost in the evaluation and LCA.” For this criterion to be properly evaluated, one requires information about the quantity, dimensions, and availability of the products. It is also important to know how to handle and care for a product during storage. Storage and logistics may affect the risk evaluation (g). In Nøstebukten Brygge, there is no available place for storing large amounts of materials prior to reuse. The contractor is responsible, in this phase, for planning the dismantling and finding a temporary storage site for the reclaimed materials that will be reused in the new project. According to the project participants, Products 1, 2, and 3 require storage. It is not possible to plan for the storage of Product 1 because information about its quantity is missing. The ceiling panels (Product 2) are 100 units in number, and they must be stored in a place with low humidity. The wood floor must be stored in a place with controlled humidity and temperature.

4.1.2.6. Location in the project. This evaluation considers where to place the reclaimed products in the new project. In Nøstebukten Brygge, the project owner and architects intend to reuse reclaimed products in commercial and private areas, for example, apartments. Evaluating the location of a reclaimed product in the new project requires continuous interaction and collaboration between architects, project owners, and contractors. It is necessary to collect comprehensive documentation and information about the reclaimed products, but it is also important to have a preliminary version of the project. At this stage, the project team had not yet identified where to reuse Product 1, due to missing information and a lack of compliance with technical requirements. The ceiling panels (Product 2) can be reused in the stairwell in the new project if the product satisfies technical requirements. Finally, Product 3 can be reused in commercial areas.

4.1.2.7. Risk evaluation. It is important to evaluate and quantify the risk associated with the reuse of construction products. One interviewee stated, “Reuse is risky because it implies a new, innovative way of thinking.” The reuse process involves a certain economic risk, which is related to the longer time period needed for planning and logistics; a technical risk, which is related to product performance and life expectancy, and an initial level of uncertainty due to the lack of information and data. In a circular project, it is therefore important to plan the contingency accordingly. One interviewee said, “For example, if you are going to reuse five windows in the new project, then you should at least have seven or eight windows available in case some will no longer be suitable for reuse due to bad conditions or problems during storage.” According to the project participants, it is also important to define, based on the initial phase of the reuse process, who bears the responsibility for reuse in the project. The risk of reusing Products 1, 2, and 3 is influenced by the lack of information and uncertainty, potential extra costs associated with storage and testing, quality, and life expectancy.

4.1.2.8. Cost evaluation. As mentioned above, the reuse of construction products often implies an extra cost for the project. Cost evaluation is important in deciding which products can be reused and how. This evaluation is affected by other factors, such as the logistics, quality, and condition of the product; risk-related factors; and opportunities for reuse. The project participants were convinced that financial factors should not be the only driver of CE implementation, but this evaluation often had high relevance during discussions. This parameter is contingent on the context of the project, and detailed information about products and project design are necessary for evaluation. At this stage, the project participants did not estimate the cost of reusing Products 1, 2, and 3. However, considering the uncertainty involved, high costs for storage and testing were expected.

4.1.3. Plan for reuse

Step 3 entailed planning for the reuse of the identified construction products. In this phase, it is important to conduct technical tests on the products, if needed, and plan for storage and logistics. The project participants must also define a system for information traceability, integrating it into BIM. The future building’s users accepting the inclusion of reused materials in residential areas is important for the Nøstebukten Brygge project. However, the project participants expressed concerns about being able to include reused elements inside the apartments, considering that a strong “culture” supporting reuse has not yet developed in Norway. Finally, some reclaimed products will also be traded in the external marketplace, which is in line with BREEAM requirements.

5. Discussion

The reuse of construction products is increasingly being explored as a strategy via which to achieve CE (Norouzi et al., 2021; Zatta and Condotta, 2023). The literature emphasizes the need for a better understanding of how CE is implemented in practice (Benachio et al., 2020; Charef and Emmitt, 2021), particularly concerning the supply chain for reuse (Harala et al., 2023). This study stands out for its contribution to a better understanding of the practical implications of reusing existing construction products in a circular project. The Nøstebukten Brygge case study, one of the largest reuse initiatives in Norway, involves project participants who are dedicated to improving the efficiency of the reuse process. The findings, including the three-step process and evaluation criteria, imply a focus on data management to enhance the efficiency of reuse and propose an innovative evaluations-based approach to assessing reusability in a circular project. Reusing existing construction products reduces waste and the exploitation of new resources (Benachio et al., 2020; Arora et al., 2021); therefore, this practice is often associated with CE and sustainable development. In this study, the three-step process captures only a snapshot of the entire Nøstebukten Brygge project and focuses only on the early design phase. Thus, the comprehensive implementation of reuse in practice and the achievement of CE in the project require broader application. It is important to establish strong collaboration among the project participants and adopt a systemic approach that considers the economic, environmental, organizational, and regulatory dimensions (Pomponi and Moncaster, 2017; Heisel and Rau-Oberhuber, 2020; Munaro and Tavares, 2021; Knoth et al., 2022). From a supply chain perspective, the early involvement of architects and consultants in the project is critical for an information-driven reuse process (Sandberg and Kvellheim, 2021); as one project participant mentioned, "It would be difficult for the architects to design with reused materials if they don't know which materials are available in the existing building." The definition of a clear goal for reuse and CE in the early phase of the project is also important in fostering efficient resource allocation and encouraging innovation (Byers et al., 2023).

This study provides a framework that consists of the three-step process for the reuse of construction products and the reusability matrix, but it is also based on the considerations made throughout the analysis. The framework introduces an innovative and more efficient approach to the reuse process in a circular project, specifically information-driven approach. Fig. 5 is a representation of its definition, which was intended to help achieve the research purpose.

5.1. Step 1. Assess which properties and information about construction products are available in the project

Obtaining information and data about existing products in Nøstebukten Brygge proved challenging, which hindered the reuse process. This difficulty in acquiring product information is reported in the theories of several scholars, including Munaro and Tavares (2021), Berglund-Brown et al. (2022), Çetin et al. (2023), and Byers et al.

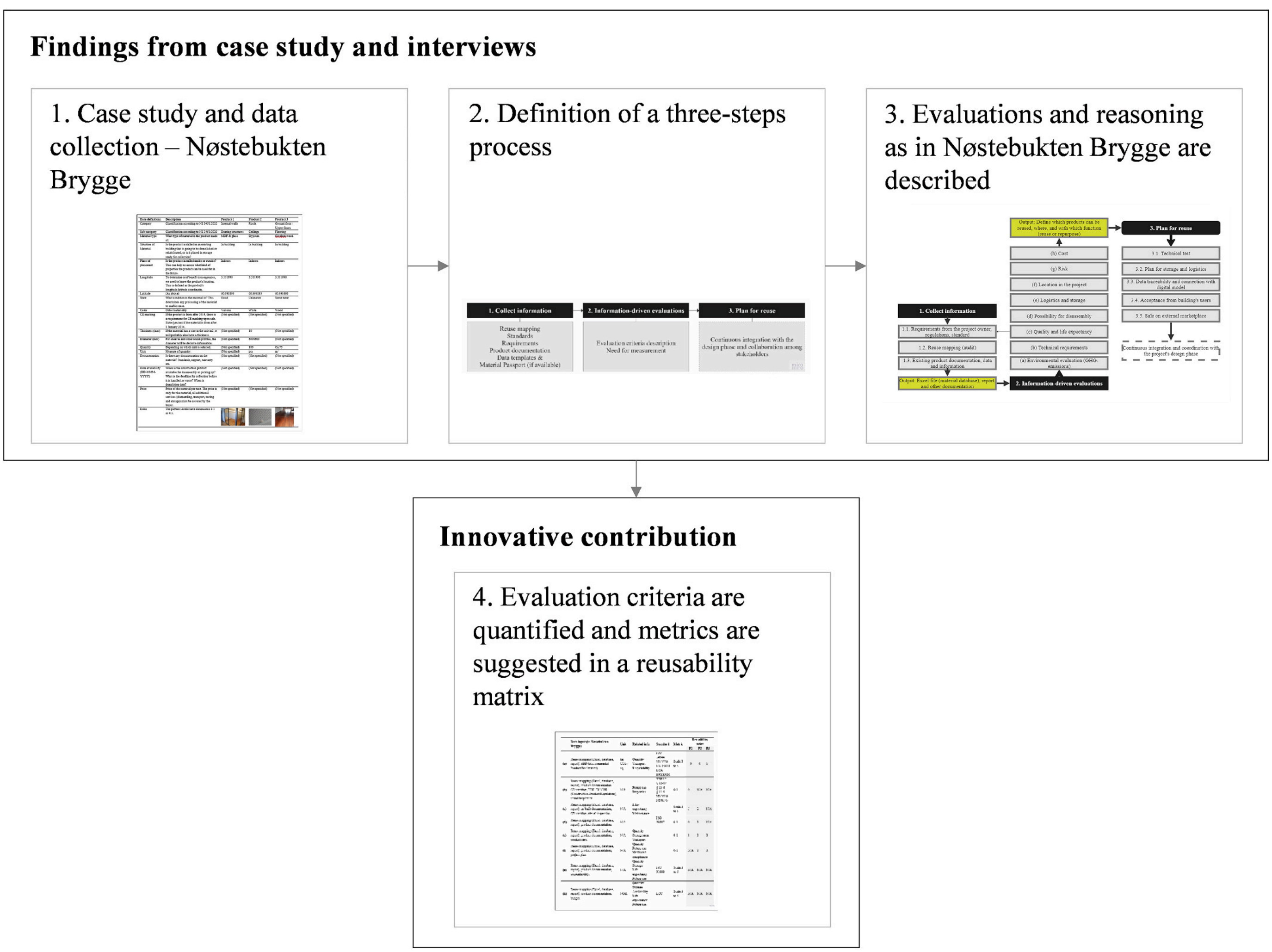


Fig. 5. Framework definition and development.

Table 7
Reusability matrix applied to case study.

	Data input (in Nøstebukten Brygge)	Unit	Related info.	Standard	Metric	Reusability index		
						P1	P2	P3
(a) Environmental evaluation	Reuse mapping, EPD (Environmental Product Declaration).	kg CO2-eq	Quantity Transport Recyclability	ISO 14044 NS 3720 EN 15978 LCA BREEAM	1 to 5	0	0	0
(b) Technical requirements	Reuse mapping, p. documentation, CE marking, EU CPR (Construction Product Regulation), visual inspection.	N/A	Future use Properties	TEK17: § 12-17 § 13-6 § 11-9 NS 3510 NS 8175	0–1	0	N/A	N/A
(c) Quality and life expectancy	Reuse mapping, as-built documentation, CE marking, visual inspection.	N/A	Life-expectancy Maintenance		1 to 5	5	2	N/A
(d) Possibility for disassembly	Reuse mapping, p. documentation.	N/A		ISO 20887	0–1	0	1	N/A
(e) Logistic and storage	Reuse mapping, p. documentation, product care.	N/A	Quantity Storage area Transport		0–1	1	1	1
(f) Location in the project	Reuse mapping, p. documentation, project plan.	N/A	Quantity Future use Needs and compliance		0–1	N/A	1	1
(g) Risk evaluation	Reuse mapping, p. documentation, accountability.	N/A	Quantity Storage Life expectancy Future use	ISO 31000	1 to 5	N/A	N/A	N/A
(h) Cost evaluation	Reuse mapping, p. documentation, budget.	NOK	Quantity Storage Availability Life expectancy Future use	LCC	1 to 5	N/A	N/A	N/A
					TOTAL	**x**	**y**	**z**

(2023). To overcome this, the project participants conducted reuse mapping and collected data from various sources, such as project documentation, technical regulations, and standards. It emerged that information about related documentation, the availability of products, and environmental parameters were not directly included in the reuse mapping, and this made it more difficult to estimate the products' reusability potential for construction products. The information-driven evaluations, (a)–(h), which were intended to assess the reusability potential, rely on available data and properties. However, despite several attempts in the literature, a standardized definition of the information necessary for this evaluation is yet to be established. Scholars such as Munaro and Tavares (2021), Berglund-Brown et al. (2022), and Byers et al. (2023) have focused on understanding which information is necessary for the reuse of construction products, considering various contexts. Byers et al. (2023) suggested property class attributes for reuse, including physical, economic, environmental, mechanical, chemical, and temporal information. This classification is aligned with the evaluation criteria defined in this study. Whereas Byers et al. (2023) affirmed that geometrical and technical data are among the most important for reuse, this study found that economic and logistics evaluations play a significant role in the decision-making process. Berglund-Brown et al. (2022) classified the information flow for CE as *technical*, including property and material data for reuse, or *commercial*, entailing the information derived from construction. Munaro and Tavares (2021) proposed a template in the form of an MP for reuse, which included categories of information such as general data, material health, sustainability, use and operational phase, historical information, and reuse potential. Improved data exchange and the increased availability of information across lifecycle stages are critical for the efficient reuse of construction products and CE (Berglund-Brown et al., 2022).

5.2. Step 2. Define a series of criteria that could be used to evaluate the reusability of a construction product

The criteria, (a)-(h), used for evaluating the reusability of a construction product were initially defined based on the experiences regarding the case study. Through a process of logical intuition, we assigned quantitative parameters to each criterion, considering the experience regarding the project, technical standards, and regulations. The outcome is a reusability matrix that was applied to the context of the case study and is represented in Table 7. Numerical parameters were assigned to each criterion, which can be summed to determine a specific construction product reusability index. This approach allows project participants to make an information-driven assessment and identify which reclaimed products have the highest potential for reuse. Whereas the reusability matrix provides a numerical basis for decision-making, it is important that additional factors be considered for each criterion and evaluated in collaboration with the project participants.

The matrix represents an original contribution, as it offers a methodology for calculating the reusability potential of a circular project. Moreover, the parameters for each criterion are based on existing standards and technical regulations and can be used as a reference throughout the project lifecycle. Several other standards, technical tests and analysis could also be implemented to evaluate the suitability of a material for reuse. However, it is beyond the scope of this study to evaluate in depth the technical factors and analyze the application of this standard in the context of the project.

The reuse of construction products is often associated with carbon-saving potentials and waste reduction (da Rocha and Sattler, 2009; Diyamandoglu and Fortuna, 2015; Nußholz et al., 2019). Nevertheless, there is still a debate in the literature regarding this connection, and some researchers, such as Geissdoerfer et al. (2017), Muñoz et al. (2023), and Figge et al. (2023), have investigated whether there is a causal relationship between reducing material usage and an improved environmental impact. The environmental evaluation (a) of Nøstebukten Brygge was not yet carried out during the early design phase. The scope of the environmental analysis should support informed decisions by demonstrating which reclaimed materials will have lower environmental impacts as compared to new products. Today, there is no single standardized way to assess the environmental benefits of reuse (Muñoz et al., 2023), but standards such as ISO 14044:2006, EN 15978:2011, and Norwegian NS 3720:2018 are often used to calculate the environmental and sustainability performance of a product or building. However, carbon footprint evaluation should be part of a comprehensive LCA methodology and include a broader spectrum of parameters (Diyamandoglu and Fortuna, 2015). In the context of a building project, it is important that the project owner clearly expresses the scope of and requirements for environmental and circularity evaluations in order to limit uncertainty. Basic requirements may include, for example, using a specific assessment tool, methodology, or software; verifying a specific environmental performance threshold; complying with specific standards; or storing information into an open-access database. The environmental analysis should consider different scenarios for reuse, including variables such as logistics, transportation, reparation, or cleaning activities. In the reusability matrix, a general scale from 1 to 5 is recommended as a metric, in which 1 indicates a lower carbon-savings potential as compared to a new product. However, it was not possible to quantify the criteria (a) for Products 1, 2, and 3, because information was missing.

Technical evaluation involves verifying the product's compliance with standards and regulations. For example, in the Nøstebukten Brygge project, Product 1 is required to adhere to the Norwegian Technical Building Regulations (TEK), specifically paragraphs § 12–17 for windows and other glass areas (Direktoratet for Byggkvalitet, 2023), as well as the Norwegian standard NS 3510:2015. Product 1 should also fulfill requirements for sound and vibrations, as expressed in TEK paragraphs § 13-6 (Direktoratet for Byggkvalitet, 2023) and in NS 8175:2012. Products 2 and 3 should comply with TEK paragraphs § 11-9 for the fire properties of materials and products (Direktoratet for Byggkvalitet, 2023). A 0–1 metric, meaning "true-false," is suggested in the reusability matrix to highlight whether the product fulfills technical requirements (=1) or not (=0).

During the early design phase, the assessment of the quality state and remaining life expectancy was conducted through visual inspection. In line with the reuse mapping, a scale from 1 to 5 was used as a metric, in which 1 = old and worn out, 2 = some wear, 3 = cleaning required, 4 = acceptable, and 5 = good. Further technical analysis and tests should be conducted to assess the remaining life expectancy of the products prior to reuse. Moreover, the disassembly potential of a construction product was also assessed in the early phase of the Nøstebukten Brygge project through visual inspection. This parameter can be quantified as 0–1, in which 0 means that the construction product cannot be disassembled. The international standard ISO 20887:2020 should be used to verify the design for disassembly and adaptability criteria in the project, as well as the potential for circularity.

In the reusability matrix, the evaluation of logistics and storage can be streamlined by adopting a 0–1 metric, in which 1 indicates that a construction product requires storage before reuse. However, quantifying this metric is a complex task, posing the risk of oversimplifying the evaluation. Thus, it is crucial to conduct additional evaluations and organize storage and logistics according to a project's specific needs. Similarly, the possibility of finding a suitable location for a construction product in the new project can be evaluated using a 0–1 metric, in which 1 indicates that it is possible to include the product in the new design. This process should also consider whether the product is being reused for the same function. The two evaluations, (e) and (f), are therefore contingent on the project context.

Finally, the risk and cost of reusing reclaimed products in a building can be influenced by several variables and factors. Therefore, it is important to adopt a structured and consistent methodology to quantify risk and cost in a circular project, considering international and national standards and guidelines. For example, one can refer to ISO 31000:2018 and methodologies for calculating lifecycle costing (LCC). In the reusability matrix, a 1–5 metric is suggested for the quantification of risk and cost, in which 5 indicates a low value and, therefore, a high potential for reuse. It was not possible to quantify criteria (g) and (h) for Products 1, 2, and 3, because information was not available during the early stage of the project.

5.3. Step 3. Suggest how to improve data management in a circular reuse process

The reuse of construction products, as a strategy via which to achieve CE in the built environment, is affected by a lack of standardized and open product data, as well as a poor systemic perspective, which makes it difficult to implement the process on a large scale (Mulhall et al., 2022; Çetin et al., 2023). Additionally, structured information flow through the value chain is critical to the successful adoption of circular strategies (Kovacic et al., 2020; Berglund-Brown et al., 2022). In the Nøstebukten Brygge project, in the early design phase, the data and information about the products were stored in static repositories (Excel or PDF format) and not integrated into a seamless information flow. As highlighted in the literature, standardized information exchange is one means of creating a circular built environment (Munaro and Tavares, 2021), and coupled with the adoption of digital technology, it is critical for the reuse process (Kovacic et al., 2020; Çetin et al., 2021; Charef and Emmitt, 2021). Several concepts, such as data templates, MPs, and digital product passports, support the digitization of product information and are key drivers of successful CE transitions (Mêda et al., 2021; Honic et al., 2024). The project participants agreed that the effective and standardized management of the information in this phase is critical in successfully reusing materials. According to one interviewee, ideally, the goal should be to collect data about the reclaimed products and automatically integrate this information into BIM. The project participants also considered the possibility of adopting material database software from an external provider. Such software provides a system for collecting data, integrating information for various stakeholders, and trading products on an external marketplace. However, when implementing an external system, it is critical for the project team to verify the traceability and accessibility of the information in the long term according to a standardized format (Bellini and Bang, 2022). Thus, the lack of information about the building in Nøstebukten Brygge complicated the evaluations of reusing construction products, which is aligned with Çetin et al. (2023). Similarly, Byers et al. (2023) highlighted the fact that there is often a mismatch between the potential of applying digital technologies to acquire information during the reuse process and their application in practice. Moreover, the fact that interoperability had not yet been fully perceived at this stage of the project could have hindered effective data management (Bellini and Bang, 2022). Another issue highlighted in the project was the need to document and communicate which materials would be available for reuse throughout the value chain, as well as in what quantities, where, and at what time this would occur. As underlined in Heisel and Rau-Oberhuber (2020), this requires a detailed dataset and can be partially resolved through the adoption of a platform for data management. In this context, the reusability matrix could also be used to verify whether information and data about existing building products are already available in the early design phase and define when and for which scope these should be accessible. Therefore, the matrix could be a first step in establishing an information-driven framework for a circular project.

6. Conclusions

This study investigated how to enhance the efficiency of the reuse process through improved data management in a circular project. The case study focuses on Nøstebukten Brygge, one of the largest projects in Norway in which the reuse of construction products is mandated to achieve circularity. For the project participants, it was challenging to determine which construction products could have been reused based on the available information and data. Construction products have various properties and characteristics, which can be difficult to compare and evaluate for reuse. From a project management perspective, the decision to reuse, repurpose, or recycle a product involves several stakeholders and impacts the entire lifecycle of an asset. The framework emerging from this study serves as a comprehensive tool for use in supporting and steering the implementation of circular reuse. The three-step process for reuse was designed based on the experience regarding the Nøstebukten Brygge project and can be used as a guide in the early design phase of a project. The process incorporates a list of eight information-driven criteria, (a)-(h), that encompass environmental, cost, logistics, and quality evaluations and are crucial in defining which elements can be reused or repurposed in the new project. For each evaluation criterion, we highlighted the available information, project requirements and expectations, and practical applications in the case study. The assessment of reusability potential is often contingent on the project context. In the case of Nøstebukten Brygge, at the time of our analysis, limited focus was placed on the environmental criteria in determining the reusability of a construction product. On the other hand, the economic and logistics criteria strongly affected the decision-making process about reuse in the project. Moreover, we specified a quantitative metric for each evaluation criterion, considering existing standards and technical regulations. The evaluation criteria and respective metrics are represented in the reusability matrix, considering the example of three reclaimed products identified in Nøstebukten Brygge. The reusability matrix represents an innovative approach, enabling project stakeholders to perform an information-driven and quantitative assessment of which reclaimed products have the highest potential for reuse. Moreover, the evaluation criteria cover various dimensions, encouraging decision-makers to adopt a systemic perspective that is beneficial in enhancing circularity. However, a lack of data about construction products in the early design phase can hinder the applicability of the matrix and, consequently, the efficiency of the reuse process. For example, in the context of the case study, it was not clear how to systematically estimate the environmental impact from a lifecycle perspective. On the other hand, the reusability matrix can also serve to assess the availability of information about existing products and materials and, within the framework, provide a structure for data management in the project.

This study reports on how the reuse process was initiated and structured during the early stage of Nøstebukten Brygge project. Based on the experience regarding the case study, the practical implication is the creation of an innovative method for assessing the reusability of construction products through information-driven evaluations. The resulting framework for and outputs of this study can be applied beyond the scope of the case study and support decision-making during the reuse process. However, the application of the three-step process and reusability matrix must be evaluated in terms of the specific project context.

6.1. Limitations and future research

Whereas the matrix introduces an original approach to measuring the reusability of construction products, its application is not always straightforward. Each evaluation should be further assessed, considering case-specific variables, such as position, requirements, and needs. The numerical parameters included as metrics were suggested by the authors of this study after a process of logical intuition, considering existing standards and technical regulations. This issue requires improvement in future research, which should focus on further assessing the framework and demonstrating a value correlation between metrics and standards, while also considering practical applications.

Although the results of this study are contextualized to the Nøstebukten Brygge project, the proposed approach and framework have the potential for generalization and application to other projects. The information needed to assess circularity is often contingent on project context, but the reusability matrix facilitates the comparison of various parameters and products. However, future research should extend these findings to other contexts and projects, potentially outside Norway, to contribute to a standardized and comprehensive framework for reuse as a CE strategy.

Finally, the methodology adopted to design the framework can be extended to include the broader application of the circular reuse process because in this case, we only focused on the early phase of the project. Nonetheless, while it is important to consider reuse as a one potential strategy via which to achieve CE, other measures and strategies should also be considered and systematically implemented in a circular construction project.

CRediT authorship contribution statement

Alessia Bellini: Conceptualization, Data curation, Investigation, Methodology, Validation, Writing – original draft. **Bjørn Andersen:** Supervision, Validation, Writing – review & editing. **Nora Johanne Klungseth:** Supervision, Validation, Writing – review & editing. **Allen Tadayon:** Supervision, Validation, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to thank PropTech Innovation and Stig-Frode Opsvik for suggesting this project as a potential case. The collaboration with Nøstebukten Brygge project, OBOS, EGD Properties, LAB, and Torstein Oen have been valuable for the development of this study. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix

Interview guide

1. Professional background and experience.
2. Specific experience with circular economy – you can shortly talk about projects and initiatives you are involved in.
3. Which type of evaluation are made in order to decide which existing materials and components can be reused from an existing building to a new one?
   - 3.1. What are the aspects to consider when deciding if an existing material or components can be reused?
   - 3.2. Which information are needed to make these evaluations?
   - 3.3. Which strategic decisions need to be made?
   - 3.4. Which stakeholders should be involved in this process? And what is their role?
   - 3.5. Is the decision based on actual data?
   - 3.6. How is the CO2 (or GHG) emissions-parameters included in the evaluation?
4. Which information or data about the reusable materials and components are needed to plan their reuse?
   - 4.1. How are this information collected, stored, and exchanged through all life cycle?
   - 4.2. Who holds this information?
5. What are the barriers connected with the reuse of materials and components in a circular building?
6. How would you define the traceability of information in this process (reuse of existing materials)?
   - 6.1. Which digital tools (software, technologies) are used in the process?
7. Which standards, requirements, legislations, guidelines are relevant for this process (reuse of existing materials)?
8. How would you define an effective process for the reuse of materials?
   - 8.1. Which steps are needed?
   - 8.2. If you look at this process (*show the process obtained through the workshop*), which considerations can you make?
   - 8.3. How is the design phase connected to the process for the reuse of materials?
9. What are the success factors for reuse of materials in a building project?
10. Anything else you would like to underline about this topic?

References

Akanbi, L.A., Oyedele, L.O., Akinade, O.O., Ajayi, A.O., Delgado, M.D., Bilal, M., Bello, S. A., 2018. Salvaging building materials in a circular economy: a BIM-based whole-life performance estimator. Conserv. Recycl. 129, 175–186. https://doi.org/10.1016/j.resconrec.2017.10.026.

Arora, M., Raspall, F., Cheah, L., Silva, A., 2019. Residential building material stocks and component-level circularity: the case of Singapore. J. Clean. Prod. 216, 239–248. https://doi.org/10.1016/j.jclepro.2019.01.199.

Arora, M., Raspall, F., Fearnley, L., Silva, A., 2021. Urban mining in buildings for a circular economy: planning, process and feasibility prospects. Resour. Conserv. Recycl. 174, 105754 https://doi.org/10.1016/j.resconrec.2021.105754.

Bell, E., Bryman, A., Harley, B., 2015. Business Research Methods. Oxford University Press, Oxford.

Bellini, A., Bang, S., 2022. Barriers for data management as an enabler of circular economy: an exploratory study of the Norwegian AEC-industry. IOP Conf. Ser.: Earth Environ. Sci., IOP Publ. 1122, 012047 https://doi.org/10.1088/1755-1315/1122/1/012047.

Benachio, G.L.F., Freitas, M.D.C.D., Tavares, S.F., 2020. Circular economy in the construction industry: a systematic literature review. J. Clean. Prod. 260, 121046 https://doi.org/10.1016/j.jclepro.2020.121046.

Berglund-Brown, J., Kedir, F., Riabova, A., Hall, D., 2022. Assessing circular information flow in industrialized construction: a framework for evaluating data for circular construction. IOP Conf. Ser.: Earth Environ. Sci., IOP Publ. 1, 012005 https://doi.org/10.1088/1755-1315/1078/1/012005.

Byers, B.S., Raghu, D., Olumo, A., De Wolf, C., Haas, C., 2023. From research to practice: a review on technologies for addressing the information gap for building. Mater. Reuse Circ.Construct. Sustain. Prod. Consumpt. 45, 177–191. https://doi.org/10.1016/j.spc.2023.12.017.

Byggallianse, Grønn, 2024. About BREEAM. https://byggalliansen.no/sertifisering/om-breeam/. assessed February 2024.

Cai, G., Waldmann, D., 2019. A material and component bank to facilitate material recycling and component reuse for a sustainable construction: concept and preliminary study. Clean Technol. Environ. Policy 21, 2015–2032. https://doi.org/10.1007/s10098-019-01758-1.

Çetin, S., De Wolf, C., Bocken, N., 2021. Circular digital built environment: an emerging framework. Sustainability 13, 6348. https://doi.org/10.3390/su13116348.

Çetin, S., Raghu, D., Honic, M., Straub, A., Gruis, V., 2023. Data requirements and availabilities for material passports: a digitally enabled framework for improving the circularity of existing buildings. Sustain. Prod. Consum. 40, 422–437. https://doi.org/10.1016/j.spc.2023.07.011.

Charef, R., Emmitt, S., 2021. Uses of building information modelling for overcoming barriers to a circular economy. J. Clean. Prod. 285, 124854 https://doi.org/10.1016/j.jclepro.2020.124854.

Chauhan, C., Parida, V., Dhir, A., 2022. Linking circular economy and digitalisation technologies: a systematic literature review of past achievements and future promises. Technol. Forecast. Soc. Change 177, 121508. https://doi.org/10.1016/j.techfore.2022.121508.

Cheshire, D., 2019. Building Revolutions: Applying the Circular Economy to the Built Environment. Routledge.

Chiaroni, D., Orlandi, M., Urbinati, A., 2021. The role of digital technologies in business model transition toward circular economy in the building industry. In: Digitalization: Approaches, Case Studies, and Tools for Strategy, Transformation and Implementation. Springer International Publishing, pp. 39–58.

Circle Economy, 2023. The Circularity Gap Report 2023. Circle Economy, Amsterdam. https://www.circularity-gap.world/2023.

Creswell, J.W., 2009. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, third ed. Sage Publications, Inc.

Creswell, J.W., Báez, J.C., 2016. 30 Essential Skills for the Qualitative Researcher. Sage Publications.

Creswell, J.W., Clark, V.L.P., 2017. Designing and Conducting Mixed Methods Research. Sage publications.
da Rocha, C.G., Sattler, M.A., 2009. A discussion on the reuse of building components in Brazil: an analysis of major social, economical and legal factors. Resour. Conserv. Recycl. 54 (2), 104–112. https://doi.org/10.1016/j.resconrec.2009.07.004.
De Wolf, C., Çetin, S., Bocken, N.M., 2024. A Circular Built Environment in the Digital Age. Springer Nature. https://doi.org/10.1007/978-3-031-39675-5.
Debacker, W., Manshoven, S., Peters, M., Ribeiro, A., De Weerdt, Y., 2017. Circular economy and design for change within the built environment: preparing the transition. Internation. HISER Conf. Adv. Recycl. Manag. Constr. Demolit Waste 114–117.
Direktoratet for Byggkvalitet (DiBK), 2023. Byggeteknisk Forskrift (TEK). https://www.dibk.no/regelverk/byggteknisk-forskrift-tek17.
Diyamandoglu, V., Fortuna, L.M., 2015. Deconstruction of wood-framed houses: material recovery and environmental impact. Resour. Conserv. Recycl. 100, 21–30. https://doi.org/10.1016/j.resconrec.2015.04.006.
Ellen MacArthur Foundation, 2013. Towards the Circular Economy Vol. 1: an Economic and Business Rationale for an Accelerated Transition. https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an.
EN 15978:2011. Sustainability of construction works - Framework for assessment of buildings and civil engineering works. https://online.standard.no/ns-en-15643-2021.
EU Commission, 2020. A New Circular Economy Action Plan. European Commission Brussels, Belgium.
Eurostat Statistical Office of the European Union, 2020. Mineral Waste from Construction and Demolition, Waste Treatment. https://www.eea.europa.eu/data-and-maps/daviz/mineral-waste-from-construction-and#tab-googlechartid_chart_13.
Figge, F., Thorpe, A., Gutberlet, M., 2023. Definitions of the circular economy-circularity matters. Ecol. Econ. 208.
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.org/10.1016/j.jclepro.2016.12.048.
Gioia, D.A., Corley, K.G., Hamilton, A.L., 2013. Seeking qualitative rigor in inductive research: notes on the Gioia methodology. Organ. Res. Methods 16 (1), 15–31. https://doi.org/10.1177/1094428112452151.
Harala, L., Alkki, L., Aarikka-Stenroos, L., Al-Najjar, A., Malmqvist, T., 2023. Industrial ecosystem renewal towards circularity to achieve the benefits of reuse-Learning from circular construction. J. Clean. Prod. 389, 135885 https://doi.org/10.1016/j.jclepro.2023.135885.
Heisel, F., Rau-Oberhuber, S., 2020. Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster. J. Clean. Prod. 243, 118482 https://doi.org/10.1016/j.jclepro.2019.118482.
Honic, M., Kovacic, I., Aschenbrenner, P., Ragossnig, A., 2021. Material passports for the end-of-life stage of buildings: challenges and potentials. J. Clean. Prod. 319, 128702 https://doi.org/10.1016/j.jclepro.2021.128702.
Honic, M., Magalhães, P.M., Van den Bosch, P., 2024. From data templates to material passports and digital product passports. In: A Circular Built Environment in the Digital Age, vol. 79. Springer Nature.
Hoosain, M.S., Paul, B.S., Raza, S.M., Ramakrishna, S., 2021. Material passports and circular economy. An introduction to circular economy. In: An Introduction to Circular Economy. Springer, pp. 131–158.
ISO 14044:2006. Environmental management. Life cycle assessment. Requirements and guidelines. https://www.iso.org/standard/38498.html.
ISO 20887:2020. Sustainability in buildings and civil engineering works. Design for disassembly and adaptability. https://www.iso.org/standard/69370.html.
ISO 31000:2018. Risk management. https://www.iso.org/standard/65694.html.
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.
Kirchherr, J., Yang, N.H.N., Schulze-Spüntrup, F., Heerink, M.J., Hartley, K., 2023. Conceptualizing the circular economy (Revisited): an analysis of 221 definitions. Resour. Conserv. Recycl. 194, 107001 https://doi.org/10.1016/j.resconrec.2023.107001.
Klungseth, N.J., Nielsen, S.B., da Graça, M.E.A., Lavy, S., 2023. Research and evidence-based standards paving the way for a digital and sustainable transformation of the built environment. Facilities 41, 454–475.
Knoth, K., Fufa, S.M., Seilskjær, E., 2022. Barriers, success factors, and perspectives for the reuse of construction products in Norway. J. Clean. Prod. 337, 130494 https://doi.org/10.1016/j.jclepro.2022.130494.
Korhonen, J., Honkasalo, A., Seppälä, J., 2018. Circular economy: the concept and its limitations. Ecol. Econ. 143, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041.
Kovacic, I., Honic, M., Sreckovic, M., 2020. Digital platform for circular economy in AEC industry. Eng. Proj. Organ. J. 9, 1–16.
Kozminska, U., 2019. Circular design: reused materials and the future reuse of building elements in architecture. IOP Conf. Ser.: Earth Environ. Sci., IOP Publ. 225, 012033 https://doi.org/10.1088/1755-1315/225/1/012033.
Mêda, P., Sousa, H., Hjelseth, E., 2020. Data templates - product information management across project life cycle. In: Sustainable Materials in Building Construction. Springer, pp. 117–133.
Mêda, P., Calvetti, D., Hjelseth, E., Sousa, H., 2021. Incremental digital twin conceptualisations targeting data-driven circular construction. Buildings 11, 554. https://doi.org/10.3390/buildings11110554.
Mulhall, D., Ayed, A.C., Schroeder, J., Hansen, K., Wautelet, T., 2022. The product circularity data sheet - a standardized digital fingerprint for circular economy data about products. Energies 15, 3397. https://doi.org/10.3390/en15093397.
Munaro, M.R., Tavares, S.F., 2021. Materials passport's review: challenges and opportunities toward a circular economy building sector. Built. Environ. Proj. Asset. Manag. 11, 767–782.
Muñoz, S., Hosseini, M.R., Crawford, R.H., 2023. Exploring the environmental assessment of circular economy in the construction industry: a scoping review. Sustain. Prod. Consum. 42, 196–210. https://doi.org/10.1016/j.spc.2023.09.022.
Nordby, A.S., 2019. Barriers and opportunities to reuse of building materials in the Norwegian construction sector. IOP Conf. Ser.: Earth Environ. Sci., IOP Publ. 225, 012061 https://doi.org/10.1088/1755-1315/225/1/012061.
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.
NS 3451:2022. Bygningsdelstabell og systemkodetabell for bygninger og tilhørende uteområder. https://online.standard.no/ns-3451-2022.
NS 3510:2015. Sikkerhetsruter i byggverk - Krav til prosjektering og klasser for ulike bruksområder. https://online.standard.no/ns-3510-2015.
NS 3720:2018. Metode for klimagassberegninger for bygninger. https://online.standard.no/ns-3720-2018.
NS 8175:2019. Lydforhold i bygninger - Lydklasser for ulike bygningstyper. https://online.standard.no/ns-8175-2019.
Nußholz, J.L., Rasmussen, F.N., Milios, L., 2019. Circular building materials: carbon saving potential and the role of business model innovation and public policy. Resour. Conserv. Recycl. 141, 308–316. https://doi.org/10.1016/j.resconrec.2018.10.036.
Pomponi, F., Moncaster, A., 2017. Circular economy for the built environment: a research framework. J. Clean. Prod. 143, 710–718. https://doi.org/10.1016/j.jclepro.2016.12.055.
Sandberg, E., Kvellheim, A.K., 2021. Ombruk Av Byggematerialer–Marked, Drivere Og Barrierer. SINTEF Akademisk forlag.
Savin-Baden, M., Major, C., 2013. Qualitative Research: the Essential Guide to Theory and Practice. Routledge. https://doi.org/10.4324/9781003377986.
Tomczak, A., v Berlo, L., Krijnen, T., Borrmann, A., Bolpagni, M., 2022. A review of methods to specify information requirements in digital construction projects. IOP Conf. Ser.: Earth Environ. Sci., IOP Publ. 1101, 092024 https://doi.org/10.1088/1755-1315/1101/9/092024.
Yin, R.K., 2018. Case Study Research and Applications. Sage.
Zatta, E., Condotta, M., 2023. Assessing the sustainability of architectural reclamation processes: an evaluation procedure for the early design phase. Build. Res. Inf. 51, 21–38. https://doi.org/10.1080/09613218.2022.2093153.