# Circular building adaptability in adaptive reuse: multiple case studies in the Netherlands



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## Abstract

**Purpose** – The application of circular building adaptability (CBA) in adaptive reuse becomes an effective action for resource efficiency, long-lasting usability of the built environment and the sped-up transition to a circular economy (CE). This paper aims to explore to which extent CBA-related strategies are applied in adaptive reuse projects, considering enablers and obstacles.

**Design/methodology/approach** – A stepwise theory-practice-oriented approach was followed. Multiple-case studies of five circular adaptive reuse projects in The Netherlands were investigated, using archival research and in-depth interviews. A cross-case analysis of the findings was deductively conducted, to find and replicate common patterns.

**Findings** – The study revealed that configuration flexibility, product dismantlability and material reversibility were applied across the case studies, whereas functional convertibility and building maintainability were less applied. Low cost of material reuse, collaboration among team members and organisational motivation were frequently observed enabling factors. Lack of information, technical complexities, lack of circularity expertise and infeasibility of innovative circular solutions were frequently observed obstacles to applying CBA.

**Practical implications** – This paper provides practitioners with a set of CBA strategies that have been applied in the real world, facilitating the application of CBA in future adaptive reuse projects. Moreover, this set of strategies provides policymakers with tools for developing supportive regulations or amending existing regulations for facilitating CE through adaptive reuse.

**Originality/value** – This study provides empirical evidence on the application of CBA in different real-life contexts. It provides scholars and practitioners with a starting point for further developing guiding or decision-making tools for CBA in adaptive reuse.

**Keywords** Adaptability, Adaptive reuse, Circular building adaptability, Circularity, Circular economy

**Paper type** Case study

## 1. Introduction

Buildings constitute a large part of the built environment and impact the use of resources, having a direct bearing on the economy and environment. Around 25% to 30% of the waste in the European Union (EU) countries is generated by the building sector (Acharya *et al.*, 2018). Thus, operationalising the circular economy (CE) in the built environment is



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important (Zimmann *et al.*, 2016). CE is a sustainable economy paradigm that eliminates waste generation and adds value to resources by adopting the R-strategies such as reuse, recycling and reduce (Kirchherr *et al.*, 2017). In light of market dynamics and population growth, many existing buildings will probably be retained and adapted, so adaptive reuse is inevitable. Adaptive reuse is known as the process of repurposing an existing building into a new function (Wilkinson *et al.*, 2014).

Adaptive reuse is sustainable for the built environment, as existing buildings can be preserved while bringing a new life to them (Bullen and Love, 2011; Marika *et al.*, 2021). Adaptive reuse also aligns with CE as it facilitates certain R-strategies (Foster, 2020). Adaptability needs to be incorporated, to sustainably facilitate the capacity to respond to future changes (Beadle *et al.*, 2008; Eguchi *et al.*, 2011). From the perspective of CE in the built environment, adaptability is fundamental for operationalising circularity in buildings (Ness and Xing, 2017), as it introduces reversibility of assets in the value chain (Geldermans, 2016). By means of adaptable design, circularity can be further facilitated (Akhimien *et al.*, 2021; Eberhardt *et al.*, 2022). Hamida *et al.* (2022) indicated that operationalising circularity and adaptability, together through the concept of circular building adaptability (CBA) in adaptive reuse is crucial to enable the built environment to withstand future changes, respond to contextual dynamics, eliminate waste generation, embody the regenerative capacity and create value out of the assets.

Previous research indicates that circularity through adaptive reuse can be effective, yet it is still emerging. Foster and Saleh (2021) found that many European policies do not align CE agendas with adaptive reuse. In a study in the Italian context, Marika *et al.* (2021) revealed that not all protocols for adaptive reuse consider CE. Kaya *et al.* (2021a, 2021b) found that there is a lack of applying circular strategies in adaptive reuse projects in The Netherlands. This immature application of CE in adaptive reuse could be attributed to the relatively short period that circularity has gained attention (Acharya *et al.*, 2018). Accordingly, policymakers, practitioners and scholars need to comprehend how circularity- and adaptability-related strategies can work in adaptive reuse projects to pave the way for circular and adaptable adaptive reuse projects in the future.

This study explores the application of CBA-strategies in adaptive reuse. This study also investigates what enables and hinders the application of these strategies. This study presents the findings of five case studies on circular adaptive reuse projects in The Netherlands. The study provides policymakers, scholars and practitioners of the circular built environment (CBE) with an understanding of how circularity and adaptability can be brought together and aligned with adaptive reuse. The findings can provide policymakers and practitioners with knowledge on how to apply circular and adaptable strategies in adaptive reuse. The findings of this study add to the relevant body of knowledge, as scholars can use the provided theory- and practice-based knowledge in developing guiding or decision-making tools for circular and adaptable building transformation.

## 2. Theoretical background

### *2.1 Circular building adaptability and its determinants and strategies*

Hamida *et al.* (2022) defined CBA as "the capacity to contextually and physically alter the built environment and sustain its usefulness, while keeping the building asset in a closed-reversible value chain", and expressed it with 10 determinants, namely, "configuration flexibility", "product dismantlability", "asset multi-usability", "design regularity", "functional convertibility", "material reversibility", "building maintainability", "resource recovery", "volume scalability" and "asset refit-ability". These determinants can be incorporated into buildings through a series of active, passive or operational strategies.

Table 1 lists a brief description of these determinants. The CBA determinants are interrelated; thus, some strategies could contribute to operationalising more than one determinant (Hamida *et al.*, 2022).

Table 2, based on an integrative literature review, illustrates a set of CBA strategies. Most of the determinants can be applied through passive strategies. Modularising and standardising the building design are effective strategies for facilitating configuration flexibility (Arge, 2005), product dismantlability (Heidrich *et al.*, 2017; Webb *et al.*, 1997), design regularity (Eberhardt *et al.*, 2022; Tserng *et al.*, 2021) and functional convertibility (Beadle *et al.*, 2008). Additionally, using dismountable building products is effective in promoting configuration flexibility (Eguchi *et al.*, 2011), product dismantlability, material reversibility (Geldermans, 2016; Ness and Xing, 2017) and asset refit-ability (Pinder *et al.*, 2017). Providing multi-purpose or sharable spaces aligns with asset multi-usability (Acharya *et al.*, 2018; Foster, 2020; Kyrö *et al.*, 2019), and functional convertibility (Arge, 2005).

Active design strategies could contribute to some determinants. For instance, providing moveable or adjustable building components contributes to configuration flexibility (Arge, 2005), and volume scalability (Bettaieb and Alsabban, 2021; Eguchi *et al.*, 2011). Operational strategies could include different determinants as well. For instance, procuring building products as a service, instead of ownership, can contribute to material reversibility, building maintainability (Iyer-Raniga, 2019; Zimmann *et al.*, 2016), and asset refit-ability (Webb *et al.*, 1997). Finally, different passive, active and operational strategies independently contribute to certain determinants Table 2. For instance, selective dismantling is a reactive strategy

| Determinant | Brief description |
|---|---|
| Configuration flexibility | The capacity to reconfigure the layout of spaces without using external resources and producing waste |
| Product dismantlability | The capacity to dismantle components and products in a building without inflicting damage and producing waste, so that they can be reused in the building or another building |
| Asset multi-usability | The capacity to offer a multiplicity of the use of building assets, so that maximising the efficiency of their utilisation |
| Design regularity | The capacity to provide a regular pattern in the spatial layout and composition of the physical assets in the building, so that facilitating the reuse and remanufacturing of the building components and products afterwards |
| Functional convertibility | The capacity to repurpose the function of a building or part of it, so that promoting its longevity while keeping its value |
| Material reversibility | The capacity to efficiently provide, use and reuse the materials in the building within a reversible value chain |
| Building maintainability | The capacity to prolong the utility of the building assets and sustain their performance |
| Resource recovery | The capacity to regenerate the building resources in a manner that reduces the use of new materials and energy consumption |
| Volume scalability | The capacity to increase and decrease the size of a building and its spaces in a response to the demands of user or organisation, so that alleviating the shortage and redundancy in the spatial use of the building |
| Asset refit-ability | The capacity to efficiently provide state-of-the-art building assets and technologies, while avoiding waste generation or over-invested solutions |

**Source:** Adapted from Hamida *et al.* (2022)

**Table 1.**
Description of the CBA determinants

| Source (Temporal order) | Strategies and their corresponding determinants | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (D1) Configuration flexibility | | | (D2) Product dismantlability | | D3 Asset multi-usability | | (D4) Design regularity | | (D5) Functional convertibility | | | (D6) Material reversibility | | | | | (D7) Building maintainability | | (D8) Resource recovery | | (D9) Volume scalability | | (D10) Asset Refit-ability | | |
| | Design standardisation* | Utilisation of adjustable building components** | Utilisation of dismountable products** | Utilisation of dismountable products** | Design standardisation* | Provision of multi-purpose space* | Provision of sharable facilities*** | Modularisation of spatial configuration* | Utilisation of standardised products* | Provision of a core for building services* | Modularisation of the building configuration* | Design for a mixed use (multifunctional) * | Utilisation of secondary (reused/ recycled) material* | Utilisation of dismountable products** | Application of material passport*** | Procurement of the service of building product*** | Selective dismantling*** | Procurement of the service of building product*** | Implementation of proactive maintenance*** | Utilisation of renewable energy technology** | Enabling the use of nature (passive) ventilation/lighting** | Design for surplus capacity* | Utilisation of movable building components** | Dematerialise the processes*** | Utilisation of dismountable products** | Procure the service of building products*** |
| (Webb *et al.*, 1997) | x | | x | x | x | | | x | x | | | | x | x | | x | | x | | | | | | | x | x |
| (Arge, 2005) | x | x | | | | x | | | | | x | x | | | | | | | x | | | | | | | |
| (Beadle *et al.*, 2008) | x | | | x | x | x | | x | x | x | | x | x | x | | | | | | | | | | | x | |
| (Eguchi *et al.*, 2011) | x | | x | x | x | | | | | | | | x | | | | | | | | | x | x | | x | |
| (Geldermans, 2016) | x | | | x | x | | | | x | | | | x | x | | | | | | | | x | | | | |
| (Manewa *et al.*, 2016) | | x | | x | | | | | | x | x | | | | | | | | | | | | x | | | |
| (Zimmann *et al.*, 2016) | | | | x | | x | x | | | x | | | x | x | x | | | | x | x | x | | | x | x | x |
| (Heidrich *et al.*, 2017) | | x | | | | | | | | | | | | | | | | | | | | | | | | |
| (Ness and Xing, 2017) | | | | x | | x | x | | | | | | x | x | | | | | | | | | | x | | x |
| (Pinder *et al.*, 2017) | x | x | | x | | | | x | | x | | | | | | | | | | | | x | | | x | |
| (Acharya *et al.*, 2018) | | | | | | x | | | | | | | x | | | | | | x | x | | | | x | | |
| (Cai and Waldmann, 2019) | | | | | | | | | | | | | x | x | x | | x | | | | | | | | | |
| (Iyer-Raniga, 2019) | | | | | | | x | | | | | | x | x | x | x | | x | | x | x | | | x | | |
| (Kyrö *et al.*, 2019) | | | | | | x | | | | x | x | x | | | | | | | | | | x | | | | |
| (Foster, 2020) | | | | x | | x | x | | | | | | x | | x | x | x | x | x | x | x | | | | | |
| (Kanters, 2020) | | | | | | | | | | | | | x | x | x | | | | | | | | | | | |
| (Akhimien *et al.*, 2021) | | | x | x | x | | | | | | | | x | x | x | | x | x | x | | | | | | | |
| (Bettaieb and Alsabban, 2021) | x | x | | | | x | | x | | | | x | | | | | | | | | | | x | | | |
| (Cottafava and Ritzen, 2021) | | | | x | | | | | | | | | x | | x | | | | | | | | | | | |
| (Tserng *et al.*, 2021) | x | | | | | | x | x | x | | | | x | | x | x | | x | x | x | x | | | x | x | x |
| (Eberhardt *et al.*, 2022) | x | | | x | | | | x | x | | | | x | x | | | | | | | | | | | | |
| ***Frequency*** | 9 | 5 | 3 | 12 | 5 | 8 | 5 | 6 | 5 | 5 | 3 | 4 | 15 | 10 | 8 | 4 | 3 | 5 | 6 | 5 | 4 | 4 | 3 | 5 | 6 | 4 |

**Notes:** *Passive strategy; **active strategy; ***operational strate

**Source:** Authors' based on the reviewed literature

**Table 2.**
CBA Strategies and their corresponding determinants

which can contribute to material reversibility in existing buildings, as it facilitates the reuse of dismantled materials somewhere else (Akhimien *et al.*, 2021; Cai and Waldmann, 2019). Applying material passports – recording the information of material used – is a strategy that facilitates material reversibility (Cottafava and Ritzen, 2021; Kanters, 2020).

### *2.2 Enabling factors*

Enabling and inhibiting factors of CBA are context-specific and could be interrelated and changeable (Acharya *et al.*, 2018; Heidrich *et al.*, 2017). For details on the reviewed literature sources for defining the enabling and inhibiting factors, see Tables A1 and A2 in the supplementary material, namely, Appendix 1 and 2. The literature review revealed six frequently mentioned enabling factors that could facilitate the application of CBA, namely.

*2.2.1 Industrial symbiosis.* Operationalising circularity in the built environment entails a process intervention on macro, meso and micro scale to control the circular flow of the building assets (Cottafava and Ritzen, 2021; Giorgi *et al.*, 2020; Ness and Xing, 2017). To facilitate product reuse for both qualities: adaptability to contextual dynamics and material circularity, industrial symbiosis could be arranged by providing and operating a collaborative market for material reuse (Cai and Waldmann, 2019; Webb *et al.*, 1997).

*2.2.2 New business models.* Industrial symbiosis is connected with another enabler, namely, the adoption of new business models for the reversibility of assets in the closed-reversible value chain (Giorgi *et al.*, 2020). Such new business models should facilitate the provision of building products as a service (Acharya *et al.*, 2018; Ness and Xing, 2017), such as providing lifts as a service (Iyer-Raniga, 2019). New business models do not only contribute to assets reversibility but also the maintainability of products that are provided as a service (Kanters, 2020).

*2.2.3 Policy/legislative support.* Policies and legislation are vital for facilitating circularity and adaptability (Acharya *et al.*, 2018; Eguchi *et al.*, 2011). Developing supportive legislation could facilitate the development of adaptable buildings (Heidrich *et al.*, 2017) or adaptability in existing premises (Manewa *et al.*, 2016). Likewise, amending existing policies and legislation has been perceived as a key requirement for operationalising CBE (Cottafava and Ritzen, 2021; Giorgi *et al.*, 2020; Kaya *et al.*, 2021b).

*2.2.4 Collaboration and partnership.* Collaboration (Cai and Waldmann, 2019), and partnership among different actors enable for developing CBE (Acharya *et al.*, 2018). Collaboration would not only facilitate operationalising CBE but also help to achieve other targets such as value creation and human-oriented development (Ness and Xing, 2017). Collaboration among stakeholders is a key to achieve material reversibility, as material looping could not be realised without effective collaboration of all actors (Iyer-Raniga, 2019). Developing strategic partnerships would contribute to further enhance the collaboration (Giorgi *et al.*, 2020; Kaya *et al.*, 2021b).

*2.2.5 Construction/design innovations.* Innovative design and construction is needed to reactively or proactively operationalise adaptability in buildings (Eguchi *et al.*, 2011; Webb *et al.*, 1997) and circularity (Acharya *et al.*, 2018; Kaya *et al.*, 2021b). Thereby, material reversibility can be realised (Iyer-Raniga, 2019; Kanters, 2020).

*2.2.6 Enabling/digital technologies.* The adoption of technologies is perceived as a key facilitator of circularity and adaptability in buildings (Giorgi *et al.*, 2020). Technology can be used to assist professionals to enhance the adaptability level in buildings (Heidrich *et al.*, 2017; Manewa *et al.*, 2016). Furthermore, digital technologies are perceived as a key enabler for CBE, as they facilitate the application of different circular strategies in buildings (Acharya *et al.*, 2018). For instance, digital technologies facilitate the application of material passports and banks (Cai and Waldmann, 2019), building operation, the provision of renewable energy systems (Acharya *et al.*, 2018) and the use of virtual resources (Iyer-Raniga, 2019).

### *2.3 Inhibiting factors – obstacles*

The integrative literature review revealed six frequently mentioned inhibiting factors that could hinder the take-up of CBA-related strategies, namely.

*2.3.1 Lack of applicable legislation/legislative restrictions.* Inadequate or rigid legislation is perceived as a legal barrier to the application of adaptability (Heidrich *et al.*, 2017) and circularity in buildings (Acharya *et al.*, 2018). Regulations tend to be a primary obstacle to building adaptability (Eguchi *et al.*, 2011). Different adaptability strategies are obstructed by the rigidity of legislation; for instance design for multi-functionality (Manewa *et al.*, 2016). The rigidity of existing legislation could limit circular strategies (Giorgi *et al.*, 2020), including selective deconstruction of building components (Cai and Waldmann, 2019), material reuse (Kanters, 2020) and design for dismantling/disassembly (DfD) (Cottafava and Ritzen, 2021).

*2.3.2 Lack of knowledge/knowledgeable practitioners in the industry.* Technical solutions associated with building adaptability and circularity are found complex and advanced and require knowledge for implementation (Acharya *et al.*, 2018; Eguchi *et al.*, 2011). However, the lack of awareness and expertise is an obstacle to the take-up of adaptable and circular strategies (Giorgi *et al.*, 2020). Lack of knowledge could also obstruct the application of key CBA-related strategies, such as circular building operation (Akhimien *et al.*, 2021), installation and reuse of reusable products (Iyer-Raniga, 2019) and use of sustainable material (Cottafava and Ritzen, 2021).

*2.3.3 Economic constraints (lack of financing).* Economic constraints and financial considerations are among the key inhibitors of building adaptability (Eguchi *et al.*, 2011) and building circularity (Giorgi *et al.*, 2020). Reasons could be the lack of financing (Acharya *et al.*, 2018; Heidrich *et al.*, 2017), cost-ineffectiveness considerations (Cai and Waldmann, 2019) and high labour cost (Kanters, 2020). Financial constraints could hinder material reuse and DfD (Kanters, 2020).

*2.3.4 Following linear economy "business as usual paradigm"/market conservativeness.* Market conservativeness further hampers the application of circular building strategies (Kanters, 2020). Stakeholders tend to follow traditional paradigms, like "business as useful", "linear economy" or "take-make-dispose model" (Acharya *et al.*, 2018). Therefore, many circular strategies are hindered, comprising material disassembly and reuse (Cai and Waldmann, 2019; Giorgi *et al.*, 2020) and multiuse of assets (Iyer-Raniga, 2019).

*2.3.5 Maladaptivity of buildings (inadaptable design, layout and construction).* Low adaptability of buildings is among the barriers to adapting existing buildings (Heidrich *et al.*, 2017) and applying circularity in the built environment (Cottafava and Ritzen, 2021). Such an obstacle could be resulted from randomly using different materials (Iyer-Raniga, 2019), also overlooking the necessity of the DfD (Giorgi *et al.*, 2020). Consequently, this could hinder material reversibility, as the material cannot be dismantled and reused (Cai and Waldmann, 2019). Further, the maladaptivity of buildings results in hampering the possibility of adaptive reuse (Manewa *et al.*, 2016).

*2.3.6 Lack of records/information on buildings.* A lack of adequate and precise building records could hinder the application of circularity (Cai and Waldmann, 2019) and adaptability in buildings (Manewa *et al.*, 2016). A reason could be that historical records on materials used in old buildings might be lacking or inaccurate (Cottafava and Ritzen, 2021). Hence, the quality of the materials cannot be determined and guaranteed (Giorgi *et al.*, 2020).

## 3. Research methodology

### *3.1 Overview*

This research adopts a qualitative case study approach (Creswell, 2013). This approach is useful for exploring emerging processes or constructed knowledge in society; thus, contributing to the relevant theory (Meyer, 2001). For example, multiple case studies can be used for exploring an emerging concept in the built environment (Conejos, 2013).

Our case study approach aimed to explore the application of CBA-related strategies in adaptive reuse. As stated by Yin (2009), the methodological approach of case study research needs to be explicitly defined and directed by theoretical propositions, to provide research validity. To develop a rigorous case study protocol, Yin's (2009) approach was followed in this paper, considering additional guidelines and recommendations (Creswell, 2013; Groat and Wang, 2013; Meyer, 2001; Saunders *et al.*, 2007). The application of CBA-related strategies in adaptive reuse was explored through multiple unitary case studies.

### *3.2 Definition of the multiple case study*

*3.2.1 Research case: the phenomenon of interest.* The phenomenon of interest in this research is the application of CBA-related strategies in circular adaptive reuse projects. According to Meyer (2001), any case should be defined, including the phenomenon of interest and its context and boundaries.

*3.2.2 Contexts and boundaries of the case.* According to Yin (2009), boundaries between a phenomenon and its context is neither completely clear nor controllable. Contexts can be described as the complex dynamics interacting with the phenomenon of interest, where the phenomenon of interest is virtually inseparable from them (Groat and Wang, 2013). In this research, multiple contexts related to building typologies – such as residential, educational, commercial and medical – and triggers for adaptive reuse – vacancy, obsolescence and change of user – were considered. According to Saunders *et al.* (2007), varying contexts could help in understanding and identifying different patterns across a heterogenous sample; thereby, expand theoretically conceptualised models.

Defining the case boundary – in terms of social, organisational or individual – is essential to direct the trajectory of case study research (Perren and Ram, 2004). In this research, the CBA-strategies are studied from the perspective of professionals who have adopted the key concepts – circularity and adaptability – and brought them together in adaptive reuse.

*3.2.3 Selection criteria.* When case study research is used to explore an emerging concept in the built environment, selecting successful cases is crucial to provide reliable insight (Conejos, 2013). Thus, the case studies were selected based on four criteria, namely:

(1) *Application of CBA-related strategies*: To study the phenomenon broadly, the case study selection needs to cover the key components of the concept under exploration. The key components of CBA are building adaptability and circularity. The CBA determinants defined by Hamida *et al.* (2022) were considered as a theory-driven criterion for selecting the cases (see Section 2.1). As the application of an emerging concept is studied, it was not expected that any case would adhere to all the determinants of CBA. Instead, a series of cases should cover the application of the ten determinants, considering that the applied strategies had to relate to at least two of the ten determinants and contribute to circularity and adaptability. This criterion was the most crucial one, as it relates to the phenomenon of interest and the pursuance of the analytical generalisability and replicability of the findings. Yin (2009) emphasised the necessity of adopting theoretical propositions in case study research to analytically generalise the findings; thereby, expanding the existing body of knowledge.

(2) *Variety of building typologies*: As CBA and its application in adaptive reuse are emerging, the inclusion of different typologies would contribute to capture different strategies and enabling and inhibiting factors. In a case study of components of a newly emerged concept in the built environment, the inclusion of diverse building projects – comprising different building typologies with different characteristics – that successfully incorporate the principles of the concept could contribute to the inclusion of a wider list of components (Conejos, 2013).

(3) *Variety of triggers for adaptive reuse*: Building changes could be triggered by different external and internal factors (Kamara *et al.*, 2020). In this regard, three major triggers for adaptive were considered, namely, property vacancy, building obsolescence and change of the end user.

(4) *Identifiable concept adopters*: The involvement of representative informants of the cases that adopted circularity and adaptability – as a key component of CBA – is a data-oriented criterion that was considered to ascertain the obtainability and reliability of data. Identifying the key informants and diversifying the sources of evidence are key data collection tactics that establish the quality of case study research (Yin, 2009). In this study, the involvement of qualified participants relied on their qualification and role in the project. Thus, the CBA-strategies were studied from the perspective of the professionals who have adopted circularity and adaptability in adaptive reuse.

The multiplicity of cases in terms of functions and triggers for adaptive reuse would pave the way for analytical generalisation, owing to the potential duplication of the findings and replication of different patterns across a heterogenous sample (Yin, 2009).

### *3.3 Data collection*

The case study research uses multiple sources of evidence to uphold its construct validity (Yin, 2009). This paper applies a stepwise data collection process in each case, using archival research and in-depth interviews, respectively.

*3.3.1 Archival research.* Each case was started with archival research. Archival research is a useful data collection method for investigating printed or digital material (Ventresca and Mohr, 2002). Archival research is supplementary to other methods for improving the trustworthiness of qualitative case study by providing longitudinal data along the research conduct (Welch, 2000).

In this research, the archival research focused on defining the case study profile and documenting the applied CBA-related strategies based on public-online material, including project webpage, project news, blogs, company reports and videos.

*3.3.2 In-depth interviews.* In each case, an in-depth interview with the concept adopter followed the archival research, in which findings of the archival research were discussed during the interviews. An in-depth interview is among the most common qualitative research methods in case study research (Ellinger *et al.*, 2005).

A coherent interview guide was developed, following the guidelines of Hennink *et al.* (2011). The interview guide comprised three sets of questions, namely, opening, key and closing questions. The opening and closing questions aimed at building the conversation at the beginning and closing it at the end of the interview. In the opening part, the interviewees were asked to answer general questions about CE and its influence on practice. In the key part, the questions covered the applied CBA strategies, and their enabling and inhibiting factors which were faced in the cases. In the closing part, the interviewees were asked about their perception of the future of adaptability and circularity in buildings. A purposive sampling was used to select the interviewees, to involve representative of the concept adopters. One interviewee was interviewed about two cases (C1 and C2), as the informant is the same concept adopter in both projects. Both projects were redeveloped by the same organisation. The interviews lasted from 1 h 22 min to 2 h 16 min. All interviews were recorded and transcribed. See Table A3 in the supplementary material for more information on the profile of the conducted interviews (Appendix 3).

*3.4 Description of the selected cases*

The selected cases met the selection criteria as shown in Table 3.

*3.4.1 Case 1 (C1): transformation of a vacant office building to mixed-residential use in Den Haag.* This adaptive reuse project was implemented to revitalise a vacant office building to a short-stay residential building while reducing its environmental impact. Different CBA-related strategies were implemented, including diversifying the use of spaces, selectively dismantling of building material, using renewable energy systems, using dismountable building products, using circular building materials and reusing existing building components.

*3.4.2 Case 2 (2): transformation of obsolete and vacant office buildings to a care centre in Harderwijk.* This adaptive reuse project was implemented to convert three obsolete and vacant office buildings into a care centre. Different CBA-related strategies were implemented, including material reuse; installing flexible partitions and using solar panels. Encouragement of co-working and engagement of families were implemented as social sustainability measures.

*3.4.3 Case 3 (C3): transformation of bank towers to mixed-use buildings in Amsterdam.* This adaptive reuse project aims to convert a 10-towers corporate facility to a mixed-use property due to a change of building occupier. The project was developed in the 1980s and used by a bank for three decades. The corporate towers were bought by a municipality when the owner decided to relocate the facility. The project has been listed as a monument. The municipality sold seven towers to a developer who could redevelop the project in a circular way while preserving the monumental elements. The municipality has transformed three towers into an international school. In the school project, different CBA-related strategies have been implemented, including repairing existing products, selectively dismantling old materials and replacing the lighting system with an energy-efficient system. In the other seven towers, the developer has refunctioned the towers into mixed-use towers by including three functions in each tower, namely, restaurants/cafes on the first floor, offices and sharable spaces on the second floor and apartments of different sizes in the upper floors.

*3.4.4 Case 4 (C4): transformation of a disused gym to an office building in Bodegraven.* The aim of this adaptive reuse project was to convert an underutilised gym to an office building while experimenting with circularity in building transformation. The applied CBA-related strategies comprise installing solar panels, using secondary material, integrating and standardising different systems in the composition of wall panels and using lightweight materials.

*3.4.5 Case 5 (C5): transformation of a vacant office building to student housing in Rijswijk.* This adaptive reuse project aims to convert a vacant office building into student housing, to overcome the shortage in student housing while coping with office oversupply. Numerous CBA-related strategies have been considered, including using secondary building products, product exchange and installing lightweight walls.

*3.5 Data analysis, interpretation and triangulation*

Inductive and deductive – data-driven and theory-driven – procedures were, respectively, used to analyse the data. Making an inductive inference following each interview is a sort of inform analysis of the collected data, which provides researchers with an initial understanding of the issues under investigation (Hennink *et al.*, 2011). Thus, this process was conducted after each interview.

As this research commenced with a literature review, followed by a qualitative exploration of a concept in real-life contexts, a deduction-oriented analytical procedure was used to analyse the data, within each case and then across the cases. This kind of procedure

**Table 3.** Mapping the selected cases to the set selection criteria

| | Cases | | | | |
|---|---|---|---|---|---|
| Criteria | (C1) | (C2) | (C3) | (C4) | (C5) |
| Application of CBA-related strategies | 9/10 CBA-related strategies | 8/10 CBA-related strategies | 6/10 CBA-related strategies | 8/10 CBA-related strategies | 6/10 CBA-related strategies |
| Variety of building typologies and triggers of adaptive reuse | Mixed-residential use | Care centre | Mixed use building | Office building | Student housing |
| Variety of triggers of adaptive reuse | Vacancy | Obsolescence | Change of owner and user | Disuse | Vacancy |
| Identifiable concept adopters | Architect and project developer | Architect and project developer | Architect and project consultant | Architect, and project and design consultant | Architect and project leader |

**Source:** Authors

is useful to anticipate and structure the data patterns, using theoretically conceptualised frameworks to code and analyse the data (Saunders *et al.*, 2007). In each case, the obtained data on the CBA strategies from the archival research and in-depth interviews were deductively analysed, using the defined CBA determinants by Hamida *et al.* (2022) to structurally guide the analysis of the strategies. Similarly, the explored enabling and inhibiting factors were analysed against the revised literature (see sub-Sections 2.2 and 2.3).

Finally, the findings were triangulated and interpreted further against the existing literature. Triangulation in qualitative research is a strategy to validate the findings by referring to the empirical observations from at least two perspectives or source (Flick, 2004). The use of existing theory as a secondary source to corroborate empirical evidence is a triangulation approach in qualitative research (Creswell, 2013).

## 4. Findings

### *4.1 Circular building adaptability strategies*

The explored cases illustrate varying levels and patterns of applying CBA strategies in adaptive reuse projects. Not all the ten determinants of CBA were applied, but collectively, the cases cover all of them (Table 4).

*4.1.1 Configuration flexibility (D1).* Configuration flexibility was apparent in all cases. Flexibility is connected with circularity, and it enables reconfiguring building components according to user preferences (Geldermans *et al.*, 2019). Across the five cases, using standardised building components and installing demountable products were the most common CBA strategies for configuration flexibility. The product demountability was applied in different components across the five cases, but it has been generally applied in the walls. Separating walls from the structure and using lightweight walls were applied.

In *C4*, innovative wall panels were produced, by adding a flexible heating system within the flexible wall panels. Furthermore, a flexible wiring system was also incorporated through detachable skirtings, to facilitate supplying individual users afterwards. Additionally, the floor plan of the new use was deliberately kept open.

*4.1.2 Product dismantlability (D2).* The application of product dismantlability was apparent, but obvious in C1, C2, C4 and C5. In these cases, dismountable interior wall panels were used. In C1, C2 and C4, the building layers were separated following the "shearing layers" concept of Brand (1994). In C1 and C2, the façade was separated from the structure. In C4, an innovative wall system was used to bring flexible panels, skirtings, heating system and wirings together. Overall, these findings corroborate literature that emphasises the role of DfD as a requirement for a circular product chain (Akhimien *et al.*, 2021; Geldermans, 2016).

*4.1.3 Asset multi-usability (D3).* Assets multi-usability was applied in C1, C3 and C5. In these cases, multi-usable or sharable facilities were provided. The shared facilities in C1 were cars and social spaces – gym and coffee areas. In C3, the shared facilities were realised in the seven towers, where co-working spaces and shared conference rooms were provided. Living rooms and kitchens were the shared spaces in C5. The strategy of assets sharing is mentioned in the literature as an application of CBE (Iyer-Raniga, 2019; Zimmann *et al.*, 2016).

*4.1.4 Design regularity (D4).* Design regularity was applied in C1, C2, C4 and C5. As the main layout of these cases is already configured, the design regularity was not applied through the building composition. Providing standardised building products was a common strategy for design regularity in these cases. The interior partitions were standardised by providing unitised walls. In C1 and C2, the layout of the interior partitions was modularised. In C5, the layout of the walls was modularised, following the modularity of the original

**Table 4.** Mapping the cases with the defined ten-determinants of CBA by Hamida *et al.* (2022)

| CBA determinant | CBA strategy | Cases (C1) | (C2) | (C3) | (C4) | (C5) |
|---|---|---|---|---|---|---|
| Configuration flexibility (D1) | Use of standardised building components | X | X | X | X | X |
| | Installation of demountable products | X | X | X | X | X |
| | Separation of walls from structure | X | X | X | X | X |
| | Open the floor plan | | | | X | |
| Product dismantlability (D2) | Use of dismountable interior wall panels | X | X | X | X | X |
| | Separation of the building layers | X | X | | X | |
| | Separation of walls from structure | X | X | X | X | X |
| Asset multi-usability (D3) | Provision of sharable spaces | X | N/A | | N/A | X |
| | Provision of multi-usable/sharable facilities | X | | X* | | |
| Design regularity (D4) | Installation of standardised building products | X | X | N/A | X | N/A |
| | Standardisation of the layout of spaces (modularisation) | X | X | | | |
| Functional convertibility (D5) | Design for multi-functionality | X | X | N/A | N/A | N/A |
| | Design for surplus capacity | X | X | | | |
| | Decentralisation of design | X | X | | | |
| | Modularisation of the building configuration | X | X | | | |
| Material reversibility (D6) | Use of reusable/recyclable building materials and products | X | X | X | X | X |
| | Send back discarded material for reuse or recycling | X | X | X | X | X |
| | Reuse old materials and products | X | | X | X | X |
| | Selective dismantling of old building products for reuse | X | X | X | X | X |
| | Use of second-hand building material | | | | X | X |
| | Repurpose old building materials/products | | X | | X | |
| | Product exchange | | | | | X |
| Building maintainability (D7) | Repair to old building components | N/A | N/A | X | X | N/A |
| | Preservation of monumental/old parts | | | X | X | |
| Resource recovery (D8) | Use of renewable energy systems | X | X | X** | X | N/A |
| Volume scalability (D9) | Use of dismountable building components | X | X | N/A | X | X |
| | Separation of walls from structure | X | X | | X | X |
| | Open the floor plan | | | | X | |
| Asset refit-ability (D10) | Use of dismountable building products | X | X | N/A | X | X |
| | Design for surplus capacity | X | X | | | |
| | Decentralisation of design | X | X | | | |

**Notes:** N/A = not applied; *Applied in seven towers out of ten towers (the mixed-use towers); **Applied in three towers out of ten towers (the school project)
**Source:** Authors

design. These solutions are mentioned in the literature as strategies for building circularity and adaptability (Eberhardt *et al.*, 2022).

*4.1.5 Functional convertibility (D5).* Functional convertibility was not adequately applied in the cases. This is justifiable, as Beadle *et al.* (2008) indicated that most existing buildings were developed to meet a certain demand without considering future dynamics or demands. Functional convertibility was only applied in C1 and C2. Four strategies were applied, namely, design for multi-functionality, design for surplus capacity, design decentralisation and design modularisation. The interviewee indicated that the first three strategies are closely interconnected, and were applied to facilitate functional changes. In both cases, the design for functional convertibility brought two concepts together, namely, "function free building" and "shearing layers". For the first two strategies, all possible future uses and their technical requirements were tabulated. Thereby, the adaptive reuse was designed for the maximum requirements for the first-exterior layers: site, structure and skin. Decentralising the design was applied by dividing the building services – within different building compartments – into different independent systems and shafts. Finally, the layout of the floor plans was modularised and aligned with the possible functions, using unitised building products.

*4.1.6 Material reversibility (D6).* Material reversibility was applied in all cases by using recyclable/reusable products and sending back discarded material for reuse/recycling. In C3 and C4, the material flow was closed, following the technical flow of the material cycle in the "Butterfly Diagram" (Ellen MacArthur Foundation, 2017). In C5, some of the old materials have been exchanged for second-hand materials. Providing building products as a service was applied in C1, by leasing the new facade. In C4 and C5, second-hand building products were used. The floor insulation was the second-hand product in C4, while doors and some plumbing fixtures were the second-hand products in C5.

In all cases, selective dismantling of old products and sending them for reuse/recycling were implemented. In C2, C3 – the three-school towers, C4 and C5, some of the dismantled products were reused or repurposed within the project. In C2, some of the outdated materials from the previous façade were incorporated into the floor finishes. In C4, the old heating pipes were reused in the form of stair railings, while some of the previous ducts of the heating ventilation, and air conditioning (HVAC) system were reused in decorations. Some of the windows and their frames were reused inside the building in C4. The old roof timber was reused in the construction of an additional floor in C4, also in some furniture items. In 3-school towers of C3, the ceiling tiles, walls, conduit and kitchen products were dismantled, renovated and reused. Throughout the 10-towers in C3, many lifts were repaired and reused. In C5, some of the old plumbing fixtures were reused besides the provided second-hand fixtures. In C4, the previous HVAC diffusers were reused. Cai and Waldmann (2019) indicated that selective dismantling is a circular solution for old buildings. Nevertheless, applying material passports, as a key strategy for material reuse (Zimmann *et al.*, 2016), was not applied across the cases.

*4.1.7 Building maintainability (D7).* CBA-related strategies for building maintainability are not common across the cases. The application of building maintainability was barely developed in C3 and C4 by repairing and retaining old components to prolong their use. In C3 – the threee-school towers, the ceiling tiles and many lifts were repaired and reused. In C4, the old flooring of the gym was retained and isolated. In both cases, the monumental parts were preserved. This strategy corresponds to the CE fundamental of asset longevity (Iyer-Raniga, 2019; Zimmann *et al.*, 2016). The lack of applying building maintainability strategies is possible, as Akhimien *et al.* (2021) indicated that the knowledge and strategies for applying CE in building operation are limited and need further development.

*4.1.8 Resource recovery (D8).* Resource recovery was applied in C1, C2, C4 and part of C3 – 3 of 10 towers – by installing solar panels as a renewable energy system. In C1, photo-voltaic thermal panels were installed to generate electricity, while photo-voltaic (PV) panels were used in C2, C3 and C4 to generate electricity. In C4, the installed PV panels has enabled for generating an extra amount of energy exceeding the building demand, which facilitated supplying other uses. Installing such systems to realise energy neutrality through adaptive reuse agrees with (Foster, 2020). In C3, replacing fluorescent lights with LED was implemented in the three school towers to reduce energy consumption. This strategy is in line with the circularity principle of exchanging old systems with energy-efficient alternatives (Zimmann *et al.*, 2016).

*4.1.9 Volume scalability (D9).* Volume scalability was applied in C1, C2, C4 and C5 by using dismountable building components and separating interior walls from the structure. The leased facade in C1 enables alteration in the size of apartments, where balconies could be added afterwards. In C5, lightweight partitions and some scalable walls were used. These strategies are in line with the principles of embodying adaptability and circularity in buildings (Eguchi *et al.*, 2011; Iyer-Raniga, 2019). In C4, the floor plan of most spaces has intentionally been opened to facilitate spatial division afterwards.

*4.1.10 Asset refit-ability (D10).* Asset refit-ability was applied in C1, C2, C4 and C5. The design of C1 and C2 was developed to embody surplus capacity through designing the adaptive reuse for the maximal requirements across possible uses in the future (see sub-Section 4.1.5). This strategy is common for meeting future demands (Arge, 2005; Kyrö *et al.*, 2019), also operationalising material circularity (Geldermans, 2016). In both cases, decentralising the design, through the independency of building systems and their shafts, enables for adding new systems or features afterwards. In C1, the leased façade enables physical changes, also it can be replaced. In C5, the provided second-hand lightweight walls were provided in line with their projected lifespan (10 years). Across these four cases, using dismountable building components was applied to facilitate providing new installations.

### *4.2 Enabling factors for applying circular building adaptability-related strategies*

The cross-case analysis revealed varying project- and nonproject-related enablers. The findings revealed four frequently experienced enabling factors for CBA strategies in adaptive reuse, namely:

(1) *The building characteristics*: This factor relates to the size, configuration, physical and spatial features of the building. For instance, the high strength of the gym structure in C4 facilitated the repurposing of the building into an office. The massive façade in C4 met the requirements of sound proofing for offices. In C1 and C5, the modularity of the floor plan facilitated the transformation of both buildings to residential use. The availability of a central core in C1 facilitated its re-design for multifunctionality. In C1 and C2, the ability to provide floor shafts facilitated the decentralisation of design and the design for surplus capacity. In C5, the modularity of the floor plan facilitated providing standardised partitions and second-hand plumbing fixtures. This enabler was found in the literature on building adaptability and circularity (Cottafava and Ritzen, 2021; Kamara *et al.*, 2020).

(2) *Collaboration and partnership*: Collaboration among the involved stakeholders played a vital role in applying CBA. For instance, the interviewees from C1, C2, C3 and C5 indicated that collaboration within the project and with other partners facilitated the application of circularity. In C3 and C5, the collaboration with

expertise in building circularity assisted the practitioners to determine the applicable strategies. In C1, the partnership facilitated accommodating an operational strategy, namely, the façade leasing. These findings are corroborate discussions available in the relevant literature (Acharya *et al.*, 2018; Kanters, 2020).

(3) *The presence of a motivated and capable team*: The existence of a shared aim for operationalising circularity constituted a roadmap for implementing CBA in adaptive reuse. Having a motivated owner boosted the application of CE in C3. Interviewees from C3 and C4 mentioned that having a team with a shared aim facilitated determining solutions for different problems. The interviewee from C3 gave an example of this enabler where the capability of the contactor and architect contributed to determining a solution for prolonging the use of a deteriorated cement panel. In C5, the presence of an ambitious team motivated the approaching to the concept of circularity to the project parties. All interviewees indicated that the presence of a desire for reflecting creativity in practice facilitated implementing of circularity in adaptive reuse, which agrees with relevant literature (Kanters, 2020; Kaya *et al.*, 2021b).

(4) *The economic viability of basic circular strategies*: The low cost of reusing old products motivates operationalising circularity. The low cost of using second-hand building components also attracted its application in C5. Additionally, the economic saving of reusing old material facilitated the application of circularity in C4.

### *4.3 Inhibiting factors that hinder the application of circular building adaptability-related strategies*

Similar to the enabling factors, the inhibitors could be project-related and nonproject-related factors. The findings revealed six frequent inhibiting factors for applying CBA strategies in adaptive reuse, namely:

(1) *Lack of expertise*: In C5, the interviewee indicated that hiring circularity expertise was costly for a single transformation project. This finding agrees with Kanters (2020), which indicate that skilled workers are expensive in Europe. Further, the stakeholders in C3 faced difficulty with determining the way of applying circularity during the project initiation. Overall, these findings are in line with the findings of Acharya *et al.* (2018), which indicate that a lack of knowledge of CE hinders CBE.

(2) *Technical complexities with building products and material*: Numerous technical issues associated with the circularity of building products faced by the participants. For instance, the poor construction impeded the reuse of many of old building materials in C2. The interviewee from C5 indicated that the stakeholders encountered a challenge with fitting second-hand doors and dismantling old products. In C3, the deterioration of the sanitary products hindered their reuse. These findings corroborate the findings of Iyer-Raniga (2019) and Kanters (2020), which indicate that the incompatibility of the old material is a challenge for building circularity.

(3) *Economic infeasibility of innovative/advanced strategies*: Although that the low-cost of reusing existing building components enable circularity, implementing advanced CBA strategies might be infeasible. In C4, the reuse of old heating pipes was economically infeasible, as the cost of repurposing such products in the form

of stair railings was relatively high. The interviewee from C5 indicated that the cost of the second-hand doors was cheap, but there was a need to hire a specialised carpenter to reassemble the doors, totalling a high product cost. Furthermore, the interviewee from C3 indicated that the applied taxation on the reused material makes the use of secondary products infeasible. These findings corroborate the findings of Acharya *et al.* (2018), which indicated that the financial dimension is a key barrier to CBE.

(4) *Organisations and practitioners tend to follow traditional paradigms*: The interviewees from C1, C2 and C3indicated that many organisations and practitioners tend to stick to the linear economy paradigm instead of CE. The interviewee from C3 perceived the building industry as a conservative sector. The interviewee from C1 and C2 indicated that following the linear economy paradigm and designing buildings for a single use were challenges faced in both projects. In C2, providing a smart and user-centred system was impeded by the client resistance to change. These findings agree with Kanters (2020) that revealed that market conservativeness is an obstacle to building circularity.

(5) *Lack of data and warranty on old material*: In C3, C4 and C5, the lack of records on building material and products impeded material circularity. In C4, the lack of warranty on the performance of second-hand materials constituted a concern for their use in the project. In C3, the team faced a challenge to decide on the quality of the existing building materials and their reusability, owing to the lack of building records. This finding agrees with the findings of Iyer-Raniga (2019) and Cottafava and Ritzen (2021), which indicate that there is a limitation on the transparency and adequacy of data on the performance of building materials.

(6) *Legal and legislative restrictions*: Restrictions with existing legislation constituted an inhibitor in C1, C2 and C5. The interviewee from C1 and C2 indicated that the system of the current regulations is linear, which constituted an inhibitor for applying some circular strategies in both projects. The project team of C4 could not use biobased materials, due to restrictions with the fire safety requirements, also because of the early emergence of using these products in buildings back then. These findings corroborate evidence in the relevant literature that indicates that current polices do not greatly facilitate the application of CE in buildings (Giorgi *et al.*, 2020; Kanters, 2020).

## 5. Discussions and reflections

This exploratory study investigated the extent to which CBA strategies in adaptive reuse is applied in five projects. A qualitative case study approach was followed, using two data collection techniques: archival research and in-depth interviews.

CBA has been operationalised at different levels across the cases. This could be attributed to the pivotal role of the Dutch initiatives in the transition to CE, as The Netherlands has been perceived as a pioneering arena in bringing circular principles into real actions (Kanters, 2020; Tserng *et al.*, 2021). In the overview (Table 4), three determinants were operationalised in all cases, two barely operationalised in two cases while the other five determinants were operationalized at various levels:

(1) First, that "configuration flexibility", "product dismantlability", and "material reversibility" were applied in all cases. Using recyclable/reusable products, installing dismountable products and sending back old material for reuse/

recycling were common CBA strategies across the cases. This could be attributed to the fact that passive and active strategies are possible, as the findings also revealed that building attributes constituted an enabler for CBA strategies. Furthermore, material reversibility is a principle aspect of building circularity, similar to configuration flexibility in building adaptability (Hamida *et al.*, 2022).

(2) Second, building maintainability was barely applied in two cases. This could be attributed to the fact that operational CBA strategies are yet emerging, as Akhimien *et al.* (2021) revealed that knowledge of CE strategies related to building operation is still immature. Likewise, "functional convertibility" was applied in two cases. The low application of functional convertibility across the other cases could be attributed to market conservativeness as revealed in this study, also to the societal tendency to design buildings for a single use as found by Beadle *et al.* (2008).

(3) Third, the cross-case analysis indicated that there is a variance in applying the other CBA determinants, owing to context- and building-specific circumstances. For instance, design regularity and building scalability could be restricted by the original building design and functional use of spaces (Bettaieb and Alsabban, 2021).

Further field observation might be required, as our data is limited to archival research and in-depth interviews. Field observation can follow the data collection in case study research, thereby getting a deeper grasp on case-specific influences on a phenomenon of interest (Ellinger *et al.*, 2005).

## 6. Summary, conclusion and recommendations

Building adaptability and adaptive reuse contribute to CE and CBE. Therefore, applying CBA in adaptive reuse is helpful for the transition to CBE and CE, also for fulfilling long- and short-term benefits, such as long-lasting building functionality and value addition.

This paper investigated the application of CBA strategies in adaptive reuse and frequently encountered enablers and inhibitors, following a stepwise approach combining theory and practice. Firstly, a literature review was conducted to define the CBA strategies and their enabling and inhibiting factors. Secondly, a qualitative approach of the multiple-case study was followed, using archival research and in-depth interviews as data sources. Five circular adaptive reuse projects in The Netherlands were explored.

Three determinants of CBA have been applied in all cases, namely, configuration flexibility, product dismantlability and material reversibility. However, building maintainability and functional convertibility were not adequately applied. These were barely applied in two cases. The other five determinants have been applied at varying levels.

Enabling and inhibiting factors for CBA in adaptive reuse tend to be case-specific, as some of them were project-related factors while others were not project-related factors. Moreover, some of the enabling and inhibiting factors were interrelated and changeable, such as economy- and knowledge-related factors. Low cost of material reuse, collaboration and organisational motivation were the most frequently mentioned enabling factors. Lack of information, technical complexities, lack of circularity expertise, infeasibility of sophisticated circular solutions and legislative restrictions were frequently mentioned inhibitors.

Ultimately, the conclusion of this study is limited to five cases, using archival research of publicly published information and in-depth interviews, respectively, as sources of evidence. Accordingly, the findings hold a sort of limitations with the analytical generalisability, but it is worth mentioning that the observation and documentation of replicated patterns provide lessons learned from the emerging application of CBA in real practice. Therefore, this could enable scholars to use the findings to develop guiding or decision-making tools for CBA in adaptive reuse. Practitioners can get a grasp on the applicable CBA strategies in adaptive reuse, while policymakers can revise existing regulations or programmes to include guidelines for CE in adaptive reuse. More specifically, the study concludes with the following recommendations:

- Future research would need to focus on developing and applying practical tools that can guide the application of CBA, considering governance, market and culture. Furthermore, field observations or participatory research might be useful to get a deeper grasp on contextual dimensions.
- CBA strategies for functional convertibility and building maintainability need to be further developed and applied in adaptive reuse. This can be realised through collaboration between practitioners and scholars.
- Practitioners involved in circular adaptive reuse need to consider the application of material passports as a key strategy for material reversibility. This can be boosted by encouraging record-keeping or documentation of building information.
- As following traditional paradigms has been an obstacle to CBA, current legislations should be amended to promote implementing CBA-strategies in adaptive reuse projects.

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## Appendix 1

**Table A1.** Potential enabling factors of CBA found in the relevant literature

| Source (Temporal order) | Enabling factors Industrial symbiosis | New business models | Policy/ legislative support | Collaboration and partnership | Construction/ design innovations | Enabling/ digital technologies |
|---|---|---|---|---|---|---|
| Webb *et al.* (1997) | X | | | | X | |
| Eguchi *et al.* (2011) | | | X | | X | |
| Manewa *et al.* (2016) | | | X | | | X |
| Heidrich *et al.* (2017) | | | X | | | X |
| Ness and Xing (2017) | X | X | | X | | |
| Acharya *et al.* (2018) | | X | X | X | X | X |
| Cai and Waldmann (2019) | X | | | X | | X |
| Iyer-Raniga (2019) | | X | X | X | X | X |
| Giorgi *et al.* (2020) | X | X | X | X | | X |
| Kanters (2020) | | X | | | X | |
| Cottafava and Ritzen (2021) | X | | X | | | |
| Kaya *et al.* (2021b) | | | X | X | X | |
| *Frequency* | 5 | 5 | 8 | 6 | 6 | 6 |

**Source:** Developed by the authors' based on the reviewed literature

## Appendix 2

**Table A2.** Potential inhibiting factors of CBA found in the relevant literature

| Source (Temporal order) | Inhibiting factors: Lack of applicable legislation/ legislative restrictions | Lack of knowledge/ knowledgeable practitioners in the industry | Economic constraints (lack of financing) | Following linear economy "business as usual paradigm"/ market conservativeness | Maladaptivity of buildings (inadaptable design, layout and construction) | Lack of records/ information on buildings |
|---|---|---|---|---|---|---|
| Eguchi *et al.* (2011) | X | X | X | | | |
| Manewa *et al.* (2016) | X | | | | X | X |
| Heidrich *et al.* (2017) | X | | X | | X | |
| Acharya *et al.* (2018) | X | X | X | X | | |
| Cai and Waldmann (2019) | X | | X | X | X | X |
| Iyer-Raniga (2019) | | X | | X | X | |
| Giorgi *et al.* (2020) | X | X | X | X | X | X |
| Kanters (2020) | X | | X | X | | |
| Akhimien *et al.* (2021) | | X | | | | |
| Cottafava and Ritzen (2021) | X | X | | | X | X |
| *Frequency* | 8 | 6 | 6 | 5 | 5 | 4 |

**Source:** Developed by the authors' based on the reviewed literature

## Appendix 3

| Case | Interviewee role in the project | Qualification | Experience | Time of interview | Method |
|---|---|---|---|---|---|
| Case study 1 (C1)<br>Case study 2 (C2) | Project developer | Architect (MSc in Architecture and MSc in Real Estate and Housing) | CEO of the organisation | 1:59:03 | Face-to-face |
| Case study 3 (C3) | Project consultant | Architect | Owner of consultancy firm and consultant | 1:38:24 | Online |
| Case study 4 (C4) | Design and project consultant | Architect | Circularity advisor in the organisation | 2:16:57 | Face-to-face* |
| Case study 5 (C5) | Project leader | Architect | Chair of the organisation | 1:22:50 | Face-to-face** |

**Notes:** *The interviewee asked a close colleague to join the interviewee for translating and interpreting some questions and answers: **The interviewee asked a close colleague to join the interview for adding further clarifications
**Source:** Authors

**Table A3.** Profile of the conducted interviews

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