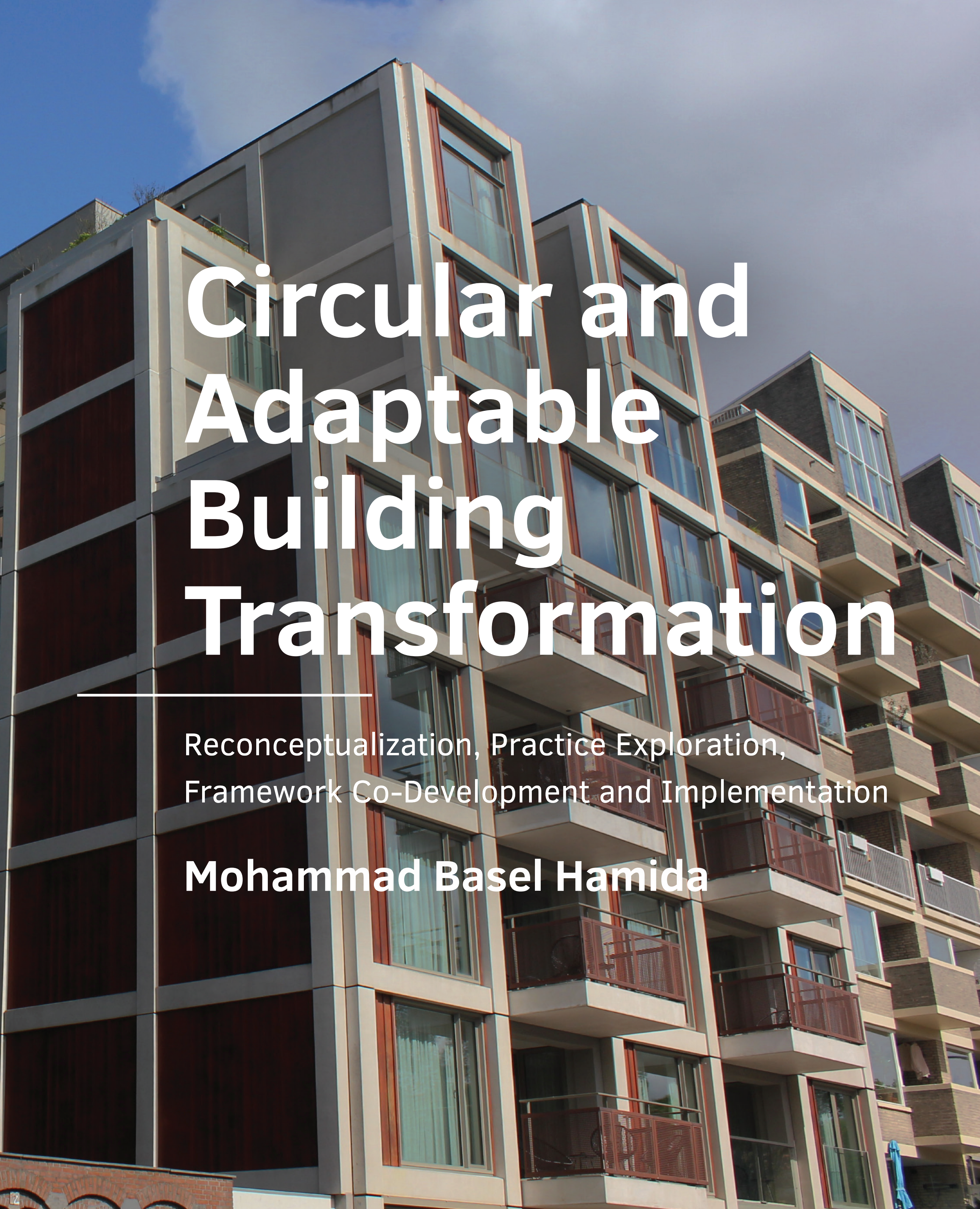

Circular and Adaptable Building Transformation

Reconceptualization, Practice Exploration, Framework Co-Development and Implementation

Mohammad Basel Hamida

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Circular and Adaptable Building Transformation

Reconceptualization, Practice Exploration, Framework Co-Development and Implementation

Dissertation

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chair of the Board for Doctorates
to be defended publicly on
Tuesday 17 June 2025 at 12:30 o'clock

by

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To the great man and leader whose wisdom and inspiration are behind all my successes, my beloved father, *Basel Hamida*.

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List of abbreviations	
AR	Action research
CE	Circular economy
CBA	Circular building adaptability
CBA-AR	Circular building adaptability in adaptive reuse
CBE	Circular built environment
DfD	Design for dismantling/disassembly
C1	Case study 1
C2	Case study 2
C3	Case study 3
C4	Case study 4
C5	Case study 5
DR	Design research
MEP	Mechanical, electrical and plumbing engineering

Glossary	
Adaptive reuse (Building transformation)	The process of converting a built-facility or part of it to a different function differing from the original use for which the facility was developed (Iselin and Lemer, 1993).
Asset multi-usability	The capacity to offer a multiplicity of the use of building assets, so that maximizing the efficiency of their utilization (Hamida *et al.*, 2023).
Asset refit-ability	The capacity to efficiently provide state-of-the-art building assets and technologies, while avoiding waste generation or over-invested solutions (Hamida *et al.*, 2023).
Building adaptability	The capacity of a building to be adapted for change or future demands (Heidrich *et al.*, 2017).
Building circularity	The capacity of building design and processes to close material chains through dynamics in the building configuration and operations (Geldermans *et al.* 2019).
Building maintainability	The capacity to prolong the utility of the building assets and sustain their performance (Hamida *et al.*, 2023).

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Glossary	
Circular building adaptability	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 (Hamida *et al.*, 2023).
Co-creation	A collaboration among different actors oriented to create meanings or meet certain needs (Ind and Coates, 2013).
Configuration flexibility	The capacity to reconfigure the layout of spaces without utilizing external resources and producing waste (Hamida *et al.*, 2023).
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 (Hamida *et al.*, 2023).
Functional convertibility	The capacity to repurpose the function of a building or part of it, so that promoting its longevity while keeping its value (Hamida *et al.*, 2023).
Material reversibility	The capacity to efficiently provide, utilize and reuse the materials in the building within a reversible value chain (Hamida *et al.*, 2023).
Product dismantlability (Demountability)	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 (Hamida *et al.*, 2023).
Resource recovery	The capacity to regenerate the building resources in a manner that reduces the use of new materials and energy consumption (Hamida *et al.*, 2023).
Volume scalability	The capacity to increase and decrease the size of a building and its spaces in response to the demands of user or organizations, so that alleviating the shortage and redundancy in the spatial use of the building (Hamida *et al.*, 2023).

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Summary

The existing building stock is not static, but consists of constantly changing assets, altered in response to various external or internal triggers for change such as physical deterioration, functional obsolescence, market volatility, technological innovations, changes in user needs, and urban and population dynamics. Thereby, change can take place in the form of adaptive reuse – also called building transformation, conversion, or across-use adaptation – or refurbishment – also called in-use adaptation. Therefore, promoting adaptability – the capacity to accommodate building changes – in transformation and refurbishment projects is promising and necessary as a means to cope with the inevitability of building alterations. In light of the calls for fostering circularity in buildings and speeding up the transition to a circular economy (CE) and circular built environment (CBE), previous research has considered building transformation a promising and effective practice contributing to CE and CBE. This is due to its great potential to reuse a large part of construction systems and components of adaptively reused buildings and prolong their utility, thereby reducing the need for extracting new materials and producing waste. Several strategies need to be implemented to promote circularity in adaptive reuse projects, and similarly, several adaptability-oriented strategies need to be implemented in this kind of building project to increase the capacity to cope with the previously mentioned triggers for change.

However, previous research pointed out that building stakeholders lack knowledge about the alignment between CE and adaptive reuse. Moreover, reviewing the relevant literature on adaptive reuse and CBE indicates that there has been no explicit consideration of aligning circularity and adaptability in the context of building transformation. More specifically, no tool has been developed to guide building and real estate professionals on the qualities of circular and adaptable adaptive reuse, along with their corresponding strategies.

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This study aims to provide building and real estate practitioners with a guiding framework for promoting circularity and adaptability in adaptive reuse projects. It answers the follwing reserach question: ***How can building adaptive reuse projects be circular and adaptable?*** A quadrant research design was developed and used in this study to develop and apply the framework in practice based on knowledge from theory and practice. The four components of this research are four stepwise studies, namely theoretical – an integrative literature review, empirical – multiple case studies, participatory – framework co-creation, and actionable – framework implementation.

First, the integrative literature review contributed to theoretically conceptualizing the underlying concept of this research, namely *circular building adaptability* (CBA), which brings together circularity and adaptability. CBA was defined 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”. It has been expressed with 10 determinants, namely configuration flexibility, product dismantlability (demountability), asset multi-usability, design regularity, functional convertibility, material reversibility, building maintainability, resource recovery, volume scalability, and asset refit-ability.

Second, the multiple case studies contributed to extracting lessons learned about applicable CBA strategies in adaptive reuse and their enabling and inhibiting factors. The study pointed out that configuration flexibility, product dismantlability, and material reversibility were promoted across the explored projects by using standardized building components, installing demountable building products, and sending back old materials and products for reuse/recycling, respectively. Low cost of material reuse, collaboration and partnership, and organizational motivation have been key enabling factors for the CBA strategies, while lack of information, technical complexities, lack of circularity expertise, and infeasibility of innovative solutions have been key inhibiting factors.

Third, the participatory study contributed to co-developing a descriptive framework for CBA in adaptive reuse (CBA-AR) based on co-creation workshops triangulated with structured interviews. The co-developed framework in this study comprises 33 CBA strategies mapped to the CBA determinants as well as to 10 enabling factors and seven inhibiting factors.

Finally, the action research study contributed to testing and improving the usability and effectiveness of the CBA-AR framework based on observing, acting, and reflecting on a case project. This study contributed to refining and expanding the co-developed framework in study 3. The CBA-AR framework was turned into a prescriptive guiding, assessment, and reporting tool, by adding other components, a stepwise approach, a user booklet, and a worksheet brought together on a user-friendly platform.

This study concludes that building transformation projects can become circular by promoting the CBA determinants. To implement this in practice, designers and real estate professionals should acquaint themselves with the CBA determinants and their corresponding strategies by iteratively using the CBA-AR framework and its worksheet as an instrument and boundary object on an interdisciplinary basis. This should consider the technical condition of the building assets as well as the applicable legislative requirements. Along with the building designers and real estate professionals, installation and MEP experts should be engaged as other specialists. Obtaining original design documents and compiling an inventory of the building assets are essential prerequisites as well for using the CBA-AR framework. It is worth noting that the developed CBA-AR framework – alongside its booklet, worksheet, and platform – cannot directly change the current practice of building transformation, but ultimately, together they pave the way for enhancing the current practice by virtue of providing practitioners with the needed knowledge in a manner tailored to their preferences.

Samenvatting

De gebouwde omgeving is geen statisch gegeven, maar bestaat uit voortdurend veranderende activa die worden aangepast als reactie op diverse externe en interne prikkels. Deze prikkels betreffen onder andere fysieke achteruitgang, functionele veroudering, marktvolatiliteit, technologische innovaties, veranderende gebruikersbehoeften en stedelijke en demografische ontwikkelingen. Veranderingen kunnen plaatsvinden in de vorm van adaptief hergebruik, ook wel gebouwtransformatie, conversie of adaptatie (met functieverandering) genoemd – of renovatie (zonder functieverandering). Het bevorderen van aanpasbaarheid – het vermogen om gebouwwijzigingen te accommoderen – binnen transformatie- en renovatieprojecten is nodig om effectief om te gaan met de onvermijdelijkheid van gebouwveranderingen.

Gezien de groeiende noodzaak om circulariteit in de gebouwde omgeving (CBE) te versterken en de transitie naar een circulaire economie (CE) te versnellen, wordt gebouwtransformatie in eerder onderzoek beschouwd als een veelbelovende en effectieve strategie die bijdraagt aan CE en CBE. Dit komt voort uit het aanzienlijke potentieel om bouwsystemen en -componenten van hergebruikte gebouwen opnieuw te benutten en hun levensduur te verlengen, waardoor de noodzaak voor de winning van nieuwe materialen en de productie van afval wordt verminderd.
Om circulariteit binnen adaptieve hergebruikprojecten te bevorderen, moeten verschillende strategieën worden geïmplementeerd. Daarnaast vereist de integratie van aanpasbaarheid in dergelijke projecten de toepassing van meerdere strategieën om hun vermogen te vergroten om in te spelen op de noodzaak van toekomstige veranderingen.

Eerder onderzoek heeft aangetoond dat belanghebbenden in de bouwsector over onvoldoende kennis beschikken met betrekking tot de afstemming tussen CE en adaptief hergebruik. Bovendien blijkt uit een analyse van de relevante literatuur over adaptief hergebruik en CBE dat de relatie tussen circulariteit en aanpasbaarheid binnen de context van gebouwtransformatie tot op heden niet expliciet is onderzocht. Meer specifiek ontbreekt een instrument dat bouw- en vastgoedprofessionals ondersteunt bij het identificeren van de kwaliteiten en bijbehorende strategieën van circulair en adaptief hergebruik.

Deze studie heeft als doel bouw- en vastgoedprofessionals een leidraad te bieden voor het bevorderen van circulariteit en aanpasbaarheid in adaptieve hergebruikprojecten. Dit onderzoek integreert daartoe theoretische en praktijkgerichte kennis en bestaat uit vier opeenvolgende deelstudies: (1) een integratieve literatuurstudie, (2) meerdere casestudies, (3) co-creatie van het raamwerk, en (4) implementatie van het raamwerk binnen een praktijkcontext.

Ten eerste heeft de integratieve literatuurstudie bijgedragen aan de theoretische conceptualisering van het centrale onderzoeksconcept: circulaire gebouwaanpasbaarheid (CBA). Dit concept brengt circulariteit en aanpasbaarheid samen en wordt gedefinieerd als "het vermogen om de gebouwde omgeving contextueel en fysiek aan te passen en de bruikbaarheid ervan te behouden, terwijl het gebouw als een gesloten-reversibele waardeketen blijft functioneren ". Dit concept werd verder uitgewerkt in tien determinanten: configuratieflexibiliteit, demonteerbaarheid van producten, multi-inzetbaarheid van activa, ontwerpregelmatigheid, functionele converteerbaarheid, materiaalreversibiliteit, onderhoudbaarheid van gebouwen, herwinning van grondstoffen, schaalbaarheid in volume en herinrichtbaarheid van activa.

Ten tweede hebben verschillende casestudies inzichten opgeleverd in de toepasbaarheid van CBA-strategieën binnen adaptief hergebruik en de factoren die deze strategieën bevorderen of belemmeren. De resultaten tonen aan dat configuratieflexibiliteit, demonteerbaarheid van producten en materiaalreversibiliteit in de onderzochte projecten werden bevorderd door het gebruik van gestandaardiseerde bouwcomponenten, de installatie van demonteerbare bouwproducten en het hergebruik of recyclen van oude materialen en producten. Daarnaast werd geconcludeerd dat een lage kostprijs voor materiaalhergebruik, samenwerking en partnerschappen, en organisatorische motivatie cruciale bevorderende factoren zijn voor CBA-strategieën, terwijl een gebrek aan informatie, technische complexiteit, een tekort aan expertise op het gebied van circulariteit en de onhaalbaarheid van innovatieve circulaire oplossingen als belangrijke belemmeringen werden geïdentificeerd.

Ten derde heeft het participatieve onderzoek bijgedragen aan de gezamenlijke ontwikkeling van een beschrijvend raamwerk voor CBA in adaptief hergebruik (CBA-AR) op basis van co-creatie workshops en gestructureerde interviews. Dit raamwerk omvat 33 CBA-strategieën, gekoppeld aan CBA-determinanten, en bevat daarnaast tien bevorderende en zeven belemmerende factoren.

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Tot slot heeft actiegericht onderzoek bijgedragen aan het testen en verfijnen van de bruikbaarheid en effectiviteit van het CBA-AR-raamwerk door middel van observatie, actie en reflectie binnen een casusproject van gebouwhergebruik. De uitkomsten van dit onderzoek hebben geleid tot de verdere ontwikkeling van het raamwerk uit de derde deelstudie. Het CBA-AR-raamwerk werd herzien en omgevormd tot een voorschrijvend instrument voor begeleiding, beoordeling en rapportage, door toevoeging van extra componenten, een stapsgewijze aanpak en een werkblad dat toegankelijk is via een gebruiksvriendelijk platform.

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1 Introduction

1.1 Background

Buildings are dynamic assets altered frequently during their lifespan. The alteration of their context and physical appearance can be triggered by external and internal factors (Kamara *et al.,* 2020). For instance, building alterations can be triggered by technological advances, market volatility, changes in user requirements (Sadafi *et al.*, 2014), building obsolescence, rapid urbanization, and climate change (Ross, 2017). However, most of the existing buildings lack adaptability – the capacity to accommodate building changes (Heidrich *et al.*, 2017), as they have been developed to meet demands and requirements in a certain period without considering future alterations or adaptations (Beadle *et al.,* 2008).

There are different forms and classifications of building alterations, including refurbishment and adaptive reuse (Shahi *et al.*, 2020), which are also known as in-use adaptation and across-use adaptation, respectively (Wilkinson, 2014). Adaptive reuse, also called building transformation, is the process of converting a building or part of it to accommodate a function differing from the original use for which it was developed (Iselin and Lemer, 1993). Therefore, it includes any intervention to adjust, reuse, upgrade or transform a building to suit new conditions or requirements of its current or new use (Remøy, 2010). Adaptive reuse is not a new practice. It has been implemented worldwide with different scenarios of transformation (Mehr 2019; Plevoets and van Cleempoel, 2019). Previous research has also shown that adaptive reuse can be implemented in existing buildings multiple times over their lifespan (Plevoets and van Cleempoel, 2019; Remøy, 2014).

Considering the call for accelerating the transition to a circular economy (CE), research has revealed that adaptive reuse is a promising practice that can promote circularity in the built environment (Foster, 2020; Foster and Saleh, 2021; Kaya *et al.*, 2021; Marika *et al.*, 2021). CE has emerged as a transformational paradigm for closing material loops, and therefore, enhancing environmental performance

(Castro *et al.*, 2022). Closing the loop in CE is realized in different ways, including implementing the R-strategies – e.g. reduce, reuse, and recycle (Kirchherr *et al.*, 2017). In this context, the alignment between CE and adaptive reuse lies in the possibility of this type of building project to facilitate the reuse of existing building assets and extend their lifespan. Consequently, this would reduce the need for extracting new material resources and minimize waste (Gravagnuolo *et al.*, 2017).

1.2 Problem statement

1.2.1 Research problem

The alignment of adaptive reuse with CE is emerging in the literature, and yet, it still requires further development. Foster (2020) and Gravagnuolo *et al.*, (2017) proposed frameworks to conceptually position adaptive reuse in CE-oriented models and provide strategies for promoting circularity in this type of building project.

Implementing adaptive reuse needs to consider integrating other contextual dimensions, along with the CE-related dimensions, to make sure that the functionality of the built environment has not been overlooked (Cerreta *et al.*, 2020; Girard, 2020), as CE tends to prioritize economic and environmental considerations over social and cultural considerations (Kirchher *et al.*, 2017).

Foster and Saleh (2021) pointed out that many European policies do not align circularity-oriented agendas with adaptive reuse. Marika *et al.* (2021) revealed that not all Italian protocols for adaptive reuse take CE into consideration. In the Netherlands, an exploratory study by Kaya *et al.* (2021) revealed that there is a lack of implementing circularity-oriented strategies in adaptive reuse projects. The same study concluded that stakeholders in adaptive reuse projects barely recognize the direct relationship between adaptive reuse and CE.

A lack of knowledge and informative tools can hinder the adoption of CE in adaptive reuse projects. Recently, based on an across-exploratory study in Europe, Pintossi *et al.* (2023) attributed this kind of practical deficiency to various challenges, mainly lack of knowledge, limitations in existing approaches, lack of collaborative processes,

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and other regulatory constraints. Accordingly, it is essential to address these challenges to foster circularity in adaptive reuse while also coping with the dynamic of this type of building project.

1.2.2 Possible solution

Introducing a change, innovation, or new actions to an unfolding practice in society is a socially constructed process that can be further brought about in different ways of solution development. This can be effectively facilitated through leveraging a collaborative process – also known as co-creation, experimentation, and action evaluation of the possible solutions (Camargo-Borges and McNamee, 2022).

Conceptual frameworks – constructed networks that link together different related concepts (Jabareen, 2009) – can be an effective knowledge-based solution for further facilitating new innovations in practice (Kivrak *et al.*, 2008). They can also be hypothesized explanatory mechanisms and a method for organizing research findings (Blaikie and Priest, 2019). In practice, frameworks can provide information resources – in the form of a specialized system of rules – facilitating the adaptation of new actions. (Hills and Gibson, 1992). Thus, they do not ensure their implementation and adoption in practice, but rather they can offer a knowledge source for action (Nilsen, 2015).

In the building industry, several frameworks were developed to capture practical knowledge for improving unfolding processes and practices such as design (Gaete Cruz *et al.*, 2022; Hassanain *et al.*, 2019; Hassanain and Juaim, 2013), building adaptation (Alauddin 2014; Hamida and Hassanain, 2022), management (Hassanain and Al-Saadi, 2005; Madritsch and Ebinger,2011) and circular built environment (Çetin *et al.*, 2021; van Stijn and Gruis, 2020). It is worth noting that many of these frameworks have been constructed to regulate or enhance certain practices by combining key concepts, actions, and other context-related considerations based on knowledge gained from theory and practice. In the built environment, these frameworks can be useful and applicable in design practices and education, as they are implicitly or explicitly created based on logical and interdisciplinary argumentation – e.g. Brand’s (1994) shearing layers model – (Groat and Wang, 2013).

Using a co-creation approach to develop a framework can be effective and contribute to the practicality and applicability of this kind of conceptualized model. For instance, Droege *et al.* (2021) followed a participatory approach to develop a framework for assessing CE performance in organizations within the Portuguese context, in which the approach contributed to tackling other considerations related to the usability of the framework. Accordingly, co-developing a guiding framework for promoting circularity in adaptive reuse projects can be an effective solution for providing policymakers, scholars, and building and practitioners with the knowledge they need to adopt this new practice.

1.2.3 Research gap

Foqué (2010) suggests that the built environment design is an outcome of three interrelated elements, namely the designer, the designed object, and the context; therefore suggesting that creating developmental frameworks considering these elements would be effective in supporting a knowledge base development. As indicated section 1.2.2, conceptual frameworks could represent constructed networks of related concepts of a given phenomenon or process (Jabareen, 2009) or a hypothesized mechanism (Blaikie and Priest, 2019). They are constructed based on different data sources and used as a lens to expect and discuss research findings (Creswell, 2021). They include the relevant components of the phenomenon, process, or mechanism of interest.

Concept-wise, relevant research has focused on positioning adaptive reuse within CE-oriented models, such as the R-ladder and ReSOLVE frameworks (see Foster, 2020; Gravagnuolo *et al.*, 2017). This focus may overlook other contextual aspects related to the functionality of built assets, as CE models can prioritize material and economic considerations over social ones (Kirchherr *et al.*, 2017). However, there has been no guiding framework developed for use in practice as a tool or boundary object providing practitioners with the needed knowledge for future-proof reuse of buildings. More specifically, there is a lack of usable knowledge- and evidence-based tools that coherently and practically provide building and real estate practitioners with the knowledge they need to promote circularity in adaptive reuse. This gap corroborates observations by Pintossi *et al.* (2023), which indicate that lack of knowledge and shortcomings in existing frameworks are among the challenges that hinder promoting circularity in adaptive reuse. Accordingly, a knowledge-based and practice-oriented tool is needed that is effective and usable in practice. As adaptive reuse projects involve different stakeholders from the building and real estate sectors – e.g. designers, developers, and investors (Wilkinson, 2014), this type of tool needs to be tailored to the preferences of these stakeholders.

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1.3 Research aim and questions

This research aims to provide practitioners from the building industry and real estate market with a guiding and knowledge-based framework for promoting circularity and adaptability in adaptive reuse projects.

The main research question of this study is:

- **How can building adaptive reuse projects be circular and adaptable?**

To answer this main research question, four sub-questions are inquired:

1. **What is the conceptual interrelationship between building circularity and adaptability?** (Chapter 2)
   This research sub-question inquiries into the interrelationship between the underlying relevant concepts to this research – circularity and adaptability – and their integration by critically examining and reviewing the literature to arrive at an integrative reconceptualization.

2. **What are the applicable circularity and adaptability strategies in adaptive reuse projects and their enablers and inhibitors?** (Chapter 3)
   This research sub-question adds to the theoretically reconceptualized interrelationships between the concepts of building circularity and adaptability by exploring the applicable strategies for promoting such quality from theory and practice along with the enabling and inhibiting factors for those strategies.

3. **What strategies and factors should be considered for circular and adaptable adaptive reuse?** (Chapter 4)
   This research sub-question builds on the gained knowledge from theory and practice in sub-questions 1 and 2 and expands it with a collaborative validation and expansion of the explored strategies and factors by participatory research with experts.

4. **How can the developed framework for circular and adaptable adaptive reuse projects be usable and effective in practice?** (Chapter 5)
   This sub-question tests the usability and effectiveness of using the developed framework in sub-question 3 as a tool for designing reuse projects for circularity and adaptability based on gaining insights from acting and observing in the real world.

1.4 Research design

As research paradigms refer to a set of theoretical and methodological traditions (Blaikie and Priest, 2019), architectural research tends to be a multidisciplinary inquiry that acquires knowledge from a wide range of research fields, thereby bringing different traditions and methods together (Groat and Wang, 2013).

As this research falls under architectural research and aims to address a problem in the real world, *pragmatism* is adopted as a research paradigm. Unlike *positivism* – assuming that knowledge is only produced based on experience and consistent observation of interrelated objects and events – or *interpretivism* – assuming that knowledge is created based on a series of actions and social meanings in a certain society over time and can be explained by using models used by the social actors engaged in these actions (Blaikie and Priest, 2019), *pragmatism* focuses on the collection of multiple data forms to answer research questions practically, to apply the findings in the real world (Creswell, 2021). Hence, *pragmatism* does not overlook philosophical assumptions of classical research paradigms. Assuming that testing research is an experience, related beliefs and actions need to be connected, and researchers can use a wide range of mixed-research methods in their inquiry (Morgen, 2014). In this regard, pragmatism can be used to answer both “what” and “how” questions of research (Islam, 2022). Finally, *pragmatism* is in line with the nature of this study (problem-solving-oriented) and considered solutions (a knowledge-based framework), because pragmatism uses knowledge as a tool for action and change-making (Murray, 2014).

An effective research design needs to align with the research questions and, therefore, adopt the relevant research methods (Blaikie and Priest, 2019). Keeping the four sub-questions (section 1.3), a 4-quadrant research design is adopted in this study to answer the four questions systematically and coherently. Figure 1.1 presents the conceptual scheme of this research, which brings together the key components and deliverables of this research. Its central concept assumes that tackling the research problem requires the following outcomes:

1. *A new reconceptualization that brings the concepts of building circularity and adaptability together.*

2. *Empirical evidence of applying the components of the underlying concepts in cases from the real world.* This is based on exploring adaptive reuse projects that manifest components of circularity and adaptability as the underlying concepts in this research study.

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3 *A co-developed knowledge-based framework for promoting the key concepts in the real world*. This outcome bridges the gap between theory and practice by the means of triangulating the theoretical and empirical observations with a co-creation–oriented process.

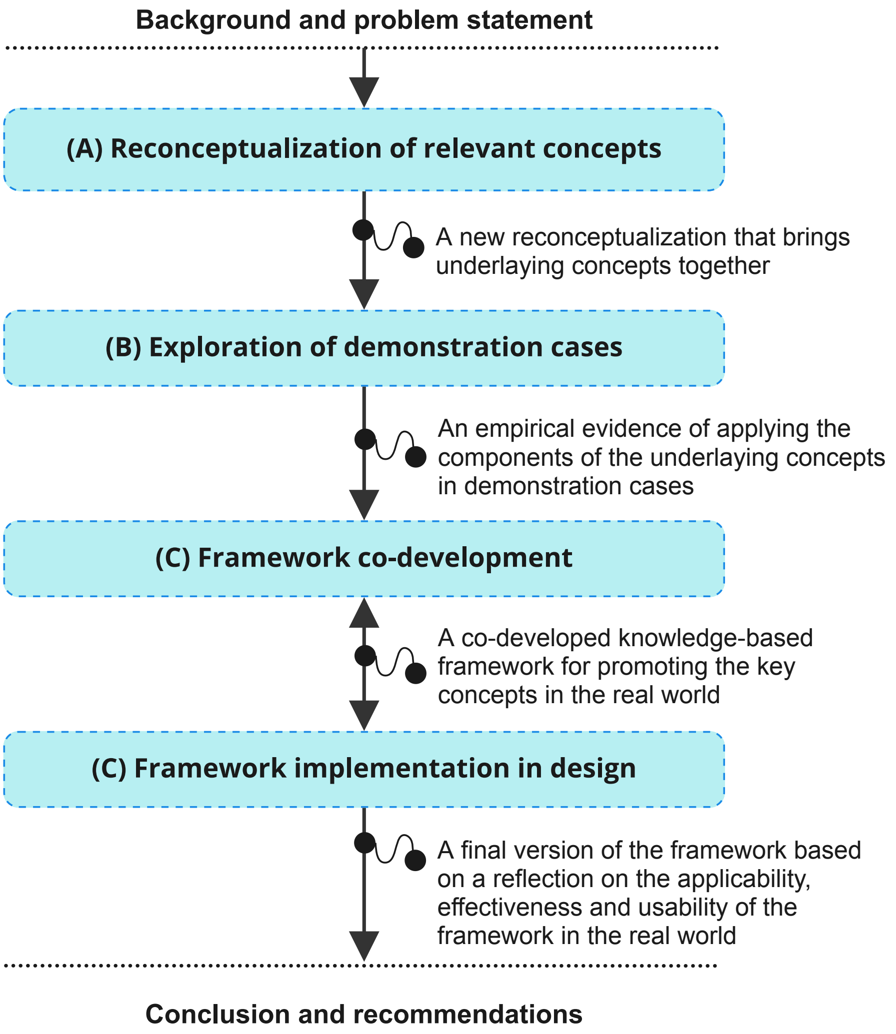
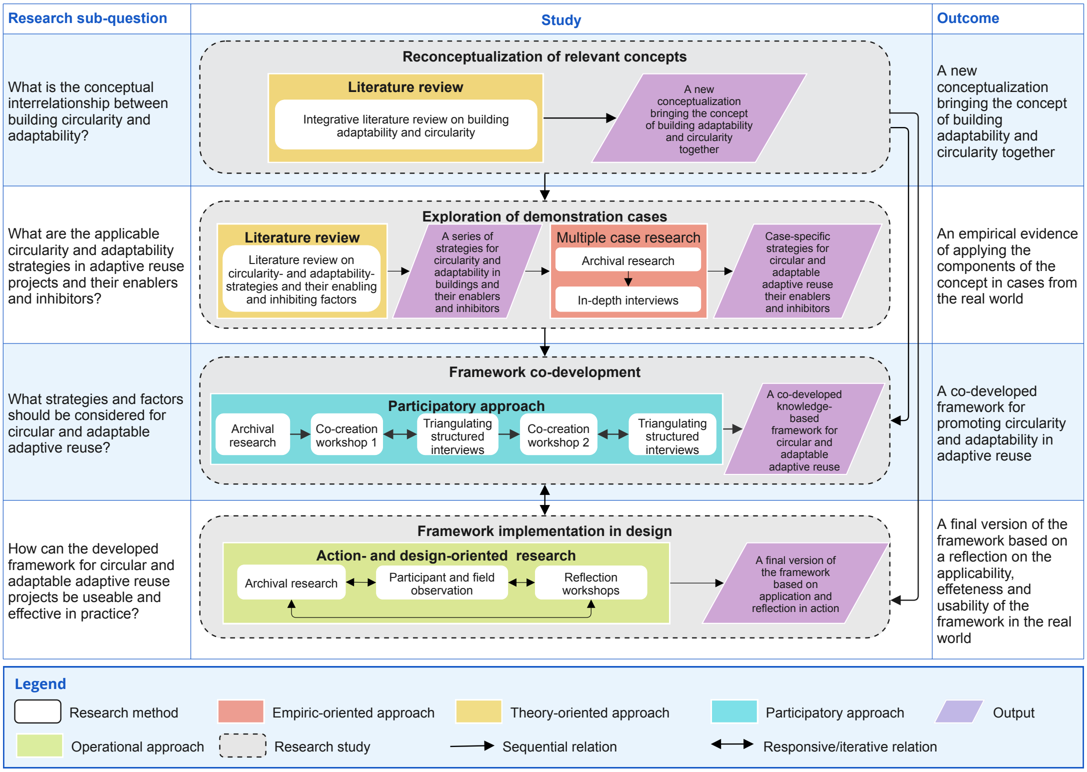


FIG. 1.1 Conceptual scheme of the research design

Based on the research scheme of this study (Figure 1.1), Figure 1.2 presents the adopted research design of this study. This research design brings together 4-stepwise studies, namely reconceptualization of relevant concepts, exploration of demonstration cases, framework co-development, and framework implementation in design. The guidelines of the Human Research Ethics Committee (HREC) at TU Delft were applied in this research.



Research sub-question	Study	Outcome
What is the conceptual interrelationship between building circularity and adaptability?	Reconceptualization of relevant concepts	A new conceptualization bringing the concept of building adaptability and circularity together
What are the applicable circularity and adaptability strategies in adaptive reuse projects and their enablers and inhibitors?	Exploration of demonstration cases	An empirical evidence of applying the components of the concept in cases from the real world
What strategies and factors should be considered for circular and adaptable adaptive reuse?	Framework co-development	A co-developed framework for promoting circularity and adaptability in adaptive reuse
How can the developed framework for circular and adaptable adaptive reuse projects be useable and effective in practice?	Framework implementation in design	A final version of the framework based on a reflection on the applicability, effeteness and usability of the framework in the real world

FIG. 1.2 Research design

1.4.1 Study 1: Reconceptualization of relevant concepts

This study aims to answer the first research sub-question: *What is the conceptual interrelationship between building circularity and adaptability?* This study is theoretical and adopts a conceptual research-oriented approach – a balance between theory-building and theory testing, by using existing descriptions, explanations, and empirical observations to formulate a concept as proposed by Meredith (1993). An integrative literature review was conducted as a method to critically reconceptualize building adaptability and combine it with the principles of circularity based on literature. In this study, Torraco's (2005) guidelines for conducting and writing an integrative literature review, with a basic aim of synthesizing conceptual frameworks or alternative models, were followed. This study is presented in Chapter 2. An in-depth methodology is provided in Section 2.4.

1.4.2 Study 2: Exploration of demonstration cases

This study aims to answer the second research sub-question*: What are the applicable circularity and adaptability strategies in adaptive reuse projects and their enablers and inhibitors?* It is an empirical-exploratory study that adopts a multiple-case approach to investigate and reveal applicable circularity- and adaptability strategies in adaptive reuse alongside the inhibiting and enabling factors for these strategies. In this study, Yin's (2009) approach to defining and designing multiple-case research was mainly followed along with additional guidelines and recommendations (Creswell, 2013; Ellinger *et al*., 2005; Groat and Wang, 2013; Meyer, 2001; Saunders *et al*., 2007). Archival research and in-depth interviews were used in each case study as data collection methods and sources of evidence. This study is presented in Chapter 3. Further information about the data collection and analysis methods is provided in Section 3.5.

1.4.3 Study 3: Framework Co-development

This study aims to answer the third research sub-question*: What strategies and factors should be considered for circular and adaptable adaptive reuse? A* participatory approach is followed in this study to collaboratively develop a knowledge-based framework for circular and adaptable adaptive reuse. Two co-creation workshops were organized, following the methodological framework by Storvang *et al*. (2018) for diagnosing, planning, facilitating, and analyzing research workshops. This study is presented in Chapter 4 Further information about the methodological settings is provided in Section 4.4.

1.4.4 Study 4: Framework implementation in design

This study aims to answer the fourth research sub-question*: How can the developed framework for circular and adaptable adaptive reuse projects be usable and effective in practice?* This study adopts an action research- and design research-oriented approach, as proposed by Collatto *et al.*, (2018), to test and reflect on the usability and effectiveness of the developed knowledge-based framework for circular and adaptable adaptive reuse. This study is presented in Chapter 5. Further information about the settings of the action and design elements is provided in Section 5.5.

1.5 Research contribution: Scientific and societal relevance

As research has conceptually placed adaptive reuse in CE models (Foster, 2020; Gravagnuolo *et al.*, 2017), this research carries theoretical and societal implications by bringing together theoretical, empirical, participatory, and actionable components systematically and coherently. First, the study critically rethinks existing and interconnected concepts – building adaptability and circularity – to come up with a new synthesis that is coherently formulated and expressed. Second, this research contributes to expanding this theoretical outcome by extracting lessons learned from demonstration cases, thereby using empirical evidence from the real world to expand the underlying concepts. Third, the study bridges the gap between theoretical and empirical observations by triangulating both outcomes with a participatory approach by adopting co-creation principles to provide practitioners, researchers, and policymakers with a knowledge-based framework for promoting the underlying concept in the real world. Finally, the developed framework has been refined based on lessons learned from testing and reflecting on its usability and effectiveness in real-world settings.

The produced outcomes and proposed recommendations in this research can provide advice for amending existing legislation and regulations of adaptive reuse, and also provide a knowledge base and instrument for building and real estate stakeholders. In the long-term, this would contribute to considerably reducing waste in transformation projects, as an ongoing type of building adaptation, while making the built environment futureproof and resource-efficient assets.

1.6 Research outline

This research is a paper-based dissertation in which four chapters are allocated to answer the four sub-questions, respectively. These four chapters are preceded by the introduction chapter and followed by the conclusion chapter (Figure 1.3). Following is an overview of the content of each chapter:

- Chapter 2 – **Circular building adaptability and its determinants - A literature review –** This chapter answers the first research sub-question through an integrative literature review aimed at critically reconceptualizing building adaptability to align it with the principles of circularity.

- Chapter 3 – **Circular building adaptability in adaptive reuse: Multiple case studies in the Netherlands –** This chapter answers the second research sub-question. It presents empirical findings of a multiple-case exploratory study that investigates and reveals the applicable circularity- and adaptability-oriented strategies in demonstration adaptive reuse projects, including the enabling and inhibiting factors to those strategies. This outcome expands the concluded theoretical reconceptualization in Chapter 2 by providing empirical evidence of promoting circularity and adaptability in adaptive reuse projects.

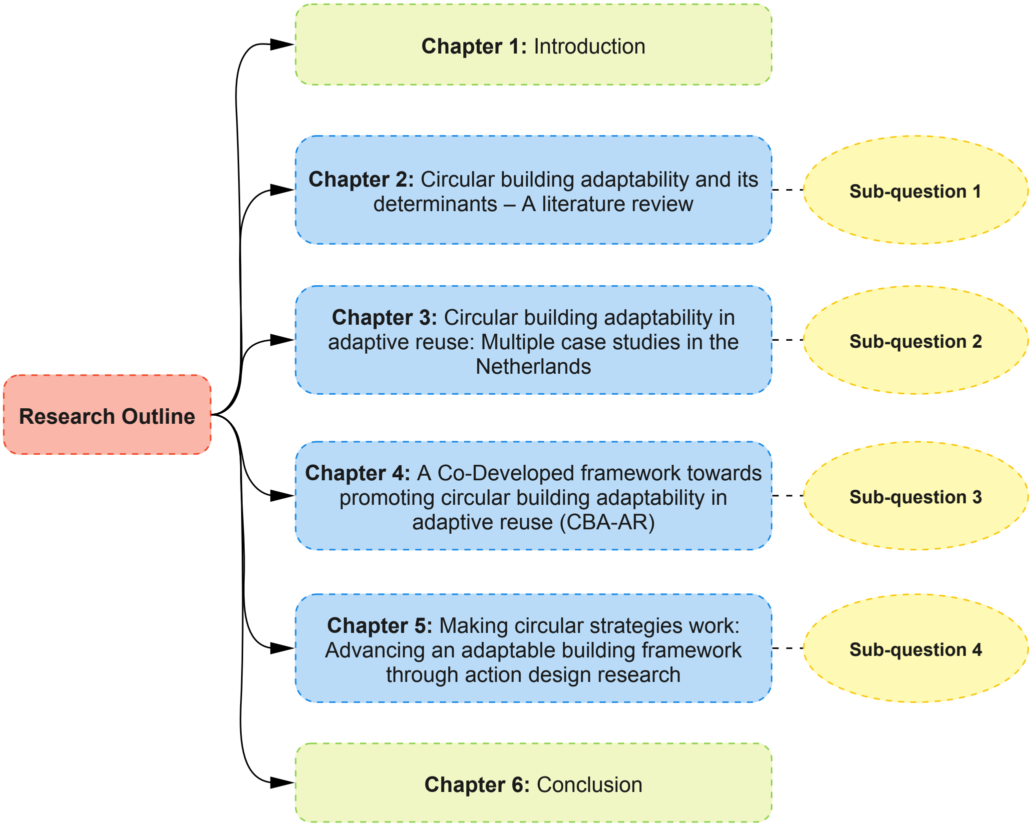


FIG. 1.3 Research outline

- Chapter 4 – **A Co-Developed framework towards promoting circular building adaptability in adaptive reuse (CBA-AR) –** This chapter answers the third research sub-question. It presents the findings of a participatory study aimed at collaboratively developing a knowledge-based framework for promoting circularity and adaptability in adaptive reuse projects. This chapter bridges the gap between the lessons learned from theory and practice in Chapter 2 and Chapter 3.

- Chapter 5 – **Making circular strategies work: Advancing an adaptable building framework through action design research – T**his chapter answers the fourth research sub-question. It presents findings of a design- and action-oriented study aimed at testing and reflecting on the applicability and effectiveness of the developed framework for fostering adaptability and circularity in adaptive reuse. This chapter presents findings of operationalizing the co-developed tool in Chapter 4 and reflects on its usability and effectiveness in the real world.

- Chapter 6 – **Conclusion –** This chapter summarizes the aim, questions, and design of this research study. The key findings and answers to each research sub-question are highlighted. This chapter puts forward recommendations for researchers, practitioners, and policymakers. Finally, this chapter indicates the limitations of this study, and therefore, it provides directions for future research.

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2 Circular building adaptability and its determinants – A literature review

2.1 Overview of chapter 2

This chapter answers the first research sub-question: What is the conceptual interrelationship between building circularity and adaptability? It combines the principles of building circularity and adaptability, the underlying concepts of this study. A conceptual research approach, referring to existing descriptions, explanations, and empirical observation within a specific body of knowledge, can be useful for theoretically conceptualizing a scheme or a classification of an event, object, or process (Meredith, 1993). Accordingly, this chapter reconceptualizes building adaptability to align it with emerging principles of circularity, using integrative literature review as a research method. Figure 2.1 illustrates the interconnection between this chapter and the conceptual scheme of this study. In the following chapters, the reconceptualization concluded in this chapter is used as the underlying concept and coding scheme, guiding data collection and structuring both the development of the framework and the alignment of its content.

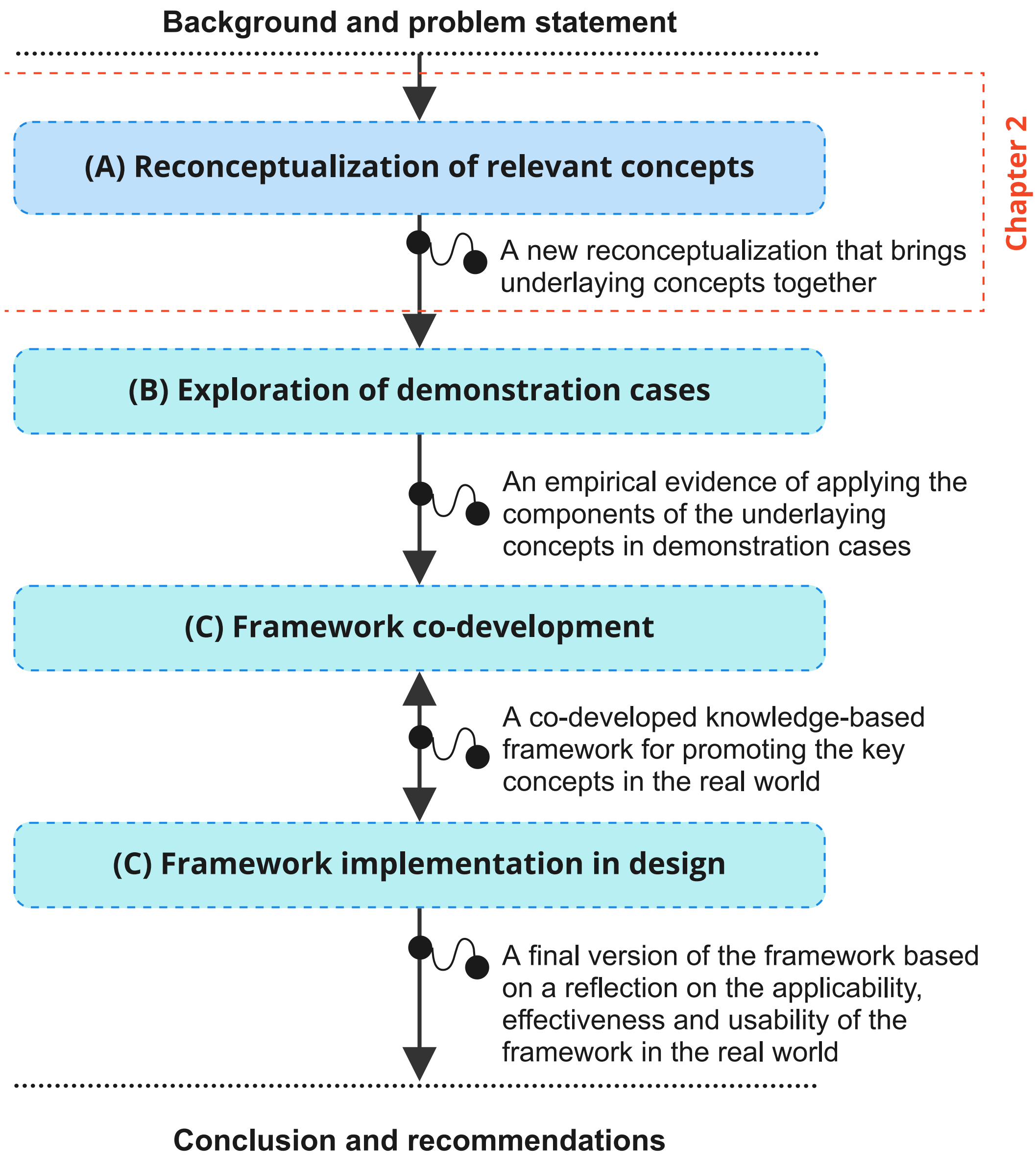

FIG. 2.1 The interconnection between Chapter 2 and the conceptual scheme of this study

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This chapter has been published as a journal paper as follows:
Hamida, M.B., Jylhä, T., Remøy, H. and Gruis, V. (2023), “Circular building adaptability and its determinants – A literature review”, In*ternational Journal of Building Pathology and Adaptation*, Vol. 41 No. 6, pp. 47-69.

In this chapter, the word “chapter” is used instead of “paper”. All headings, figures, and tables are renumbered based on the chapter number. The title of the methodology section is rephrased to be in line with the content of the chapter.

2.2 Abstract

Purpose – Adaptability is an inherent quality in building circularity, as adaptability can physically facilitate the reversibility of materials in a closed-reversible chain, also called “loops”. Nevertheless, positioning adaptability in circularity-oriented models could overlook some of the contextual considerations that contribute to the utility for the built environment. This chapter reconceptualizes building adaptability to incorporate circularity, in order to facilitate the resource loops whilst preserving the long-lasting functionality in buildings.

Design/methodology/approach – An integrative literature review on adaptability and circularity of buildings was conducted using a systematic search approach. From the initial database of 4631 publications, 104 publications were included for the final analysis. A comparative analysis of definitions and determinants of both concepts was conducted to reconceptualize circular building adaptability.

Findings – The findings of the literature study show that incorporating circularity and adaptability is possible through 10 design and operation 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. The chapter concludes that considering the defined determinants in a holistic manner could simultaneously facilitate building resilience to contextual changes, creation of asset value, and elimination of waste generation.

Originality/value – This chapter expands the relevant bodies of literature by providing a novel way of perceiving building adaptability, incorporating circularity. The practical value of this chapter lies in the discussion of potential strategies that can be proactively or reactively employed to operationalize circular building adaptability.

Keywords: Adaptability, Building adaptation, Built environment, Circularity, Circular economy, Circular building

Chapter type: Conceptual chapter

2.3 Introduction

Buildings are static objects, but need to undergo changes to respond to internal, external or building-related triggers (Kamara *et al.*, 2020). For example, changes in operation can trigger a need to add new building features or services (Estaji, 2014; Patel and Tutt, 2018). External socioeconomic changes could include changes in market dynamics (Sadafi*et al.*, 2014), demographics, climate or technology (Ross, 2017). The cultural value of many of the existing buildings also represents a key driver for preserving them (Wilkinson et al., 2014c). Thus, buildings need to be adapted to meet these changes (Slaughter, 2001). It is anticipated that the majority of existing buildings will be frequently adapted in the upcoming decades to meet future demands (Bullen, 2007; Conejos *et al.*, 2014; Perolini, 2013; Rasmussen, 2012). Consequently, it is argued that adaptability should be proactively and reactively incorporated, meaning that existing and new buildings should facilitate the accommodation of future changes (Huuhka, and Saarimaa, 2018; Langston, 2014a).

Adaptability has not only been perceived as a key quality enabling building alterations (Douglas, 2006), but also as a means to sustainable development. For instance, adaptable buildings enable the user or owner to accommodate changes in an affordable manner (Arge, 2005), while reducing the amount of waste generated from building changes (Manewa *et al.*, 2016). Adapting existing buildings is also seen as a coping strategy to deal with market-related crises, such as property oversupply (Remøy, 2014a; Waston, 2009), as well as building-related issues, such as deterioration (Langston *et al.*, 2008; Rockow *et al.*, 2019; Swallow, 1997).

TOC

Building adaptability and adaptation have recently been understood as key concepts that fit with the principles of the circular economy (CE) and a circular built environment (Ness and Xing, 2017). Building adaptability plays a vital role for reversibility of building products in the reversible chain (Geldermans, 2016). However, positioning adaptability in CE-oriented frameworks may overlook other contextual aspects, and thus, many authors emphasized the need to adopt a multidimensional framework (Cerreta *et al.*, 2020; Girard, 2020), as the CE paradigm prioritizes economic prosperity in an environmentally sustainable way, followed by fulfilling other social needs (Kirchherr *et al.*, 2017).

Literature indicates numerous determinants that articulate the capacity of a building to adapt to future demands (Arge, 2005; Eguchi *et al.*, 2011; Heidrich *et al.*, 2017), while there is a gap in integrating and aligning adaptability determinants with circularity. Considering the need to proactively and reactively incorporate and align circularity and adaptability in buildings, this study of this chapter aims to bring the concepts together. This chapter considers the adaptability of buildings for in-use and across-use adaptations.

2.4 Reconceptualization methodology: An integrative literature review

An integrative literature review, following a systematic search, was conducted to understand circular building adaptability. The integrative literature review is a useful methodology for reconceptualizing mature concepts to embody emerging developments or synthesizing a conceptual model for an emerging concept (Snyder, 2019). In this chapter, Torraco's (2005) guidelines for writing an integrative literature review – particularly the form of synthesizing conceptual frameworks or alternative models – were followed. PRISMA guidelines were followed to systematically identify, select, and report literature sources (Moher *et al.*, 2015).

2.4.1 Search strategy and screening process

The reviewed literature included peer-reviewed journal papers, conference papers and book series, and some additional grey literature sources. The systematic search was conducted in two databases: Web of Science and Scopus. In the two databases, a Boolean operator was used to combine the interrelated terms in one search query. Figure 2.2 presents the search terms and the logic of the searches. To obtain relevant sources to the research context, the terms were linked to built environment-related terms. The search was conducted in March 2021. The grey literature sources were selected to cover other relevant or supplementary sources related to adaptability and circularity.

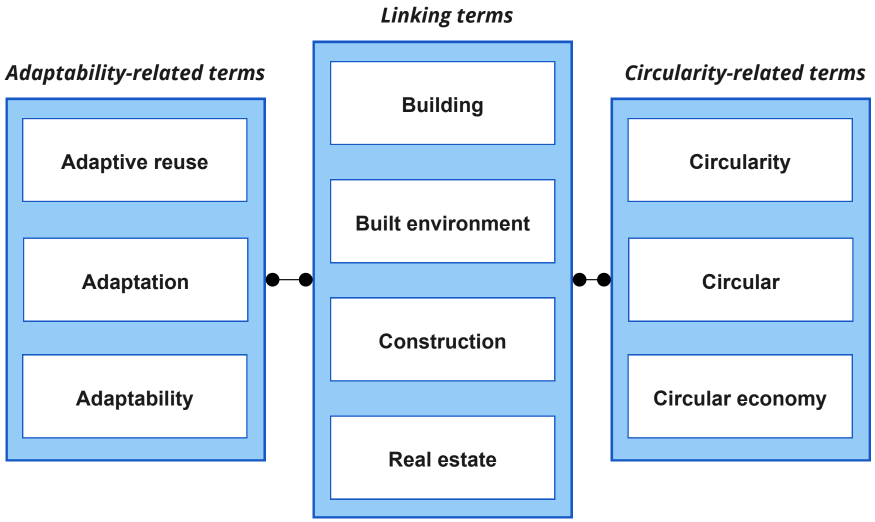

FIG. 2.2 Used search terms

Based on multiple searches, the initial database contained 7,227 papers or publications: 5,161 from Scopus; 2,052 from Web of Science; and 14 from other sources (Figure 2.3). The screening was done in three sequential phases. Each phase adopted the same inclusion and exclusion criteria (Table 2.1).

2.4.2 Integrative analysis and synthesis methods

A comparative analysis of the adaptability and circularity was conducted to define the interrelationships and contrasts between the concepts. Based hereupon, a definition of circular building adaptability was proposed. As Torraco (2005) guidelines recommend the use of a matrix to structurally guide the identification of determinants of a concept under review, two matrices were developed to present the determinants of both concepts. The integrative analysis served to recognize the overlaps, interrelationships, and dependencies between the two concepts; thus, conceptually incorporating them.

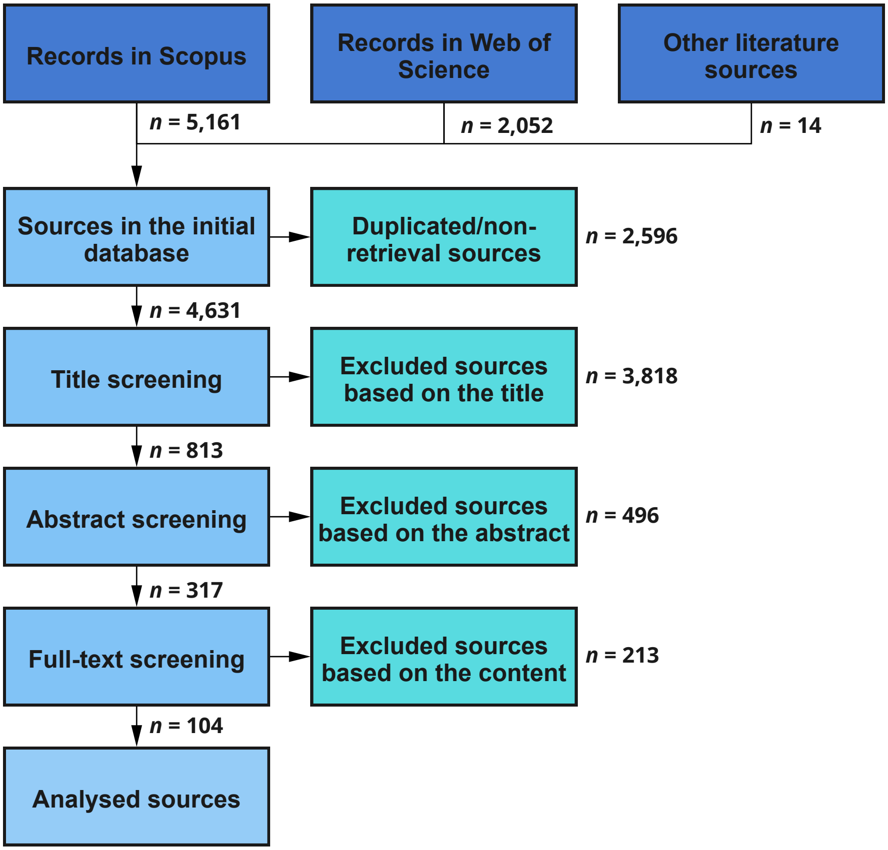

FIG. 2.3 Screening process

TABLE 2.1 Inclusion and exclusion criteria

Inclusion	Exclusion
Type of sources: Literature reviews, theoretical studies, empirical studies	**Type of sources:** Testing building material, systems or components, research methods in the built environment
Adaptability variables: Adaptable buildings, adaptability attributes, open/hybrid building design, built environment/building adaptability, adaptable strategies, fixable building design, adaptation strategies	**Adaptability variables:** Landscape adaptability, thermal adaptation, behavioral adaptation, climate change adaptation, urban economic adaptability
Circularity variables: Circular economy in the built environment, circular buildings, circular economy in construction	**Circularity variables:** Circularity and circular economy in cities, circular economy in the product chain, organization/corporate circular economy, circular economy in food chains, circular economy measurements, circular design (geometry)
Other variables: Regeneration strategies, disassembly and reusability of building components	**Other variables:** Renovation processes, vernacular heritage, housing governance, material flow analysis
Subject: Sustainable building adaptation, building adaptative reuse potential, and circular economy operationalization in the built environment	**Subject:** Adaptation of user with the building environment – e.g. thermal, lighting, acoustical, communal adaptation, and circular economy measurements.

2.5 Findings

2.5.1 Building adaptation and adaptability

Building adaptation expresses the process of altering built assets. Douglas' (2006) definition is frequently used, defining building adaptation as *"any work to a building over and above maintenance to change its capacity, function or performance (i.e. any intervention to adjust, reuse or upgrade a building to suit new conditions or requirements)."* Although the definition has been used quite often, it is generic (Wilkinson, 2014b). Thus, different categorizations were made to classify the building adaptation practice. In general, building adaptation can be categorized in terms of the level and type of intervention. Adaptation can range from minor adaptations – such as decoration or installation of fittings – to major adaptations such as building reconfiguration (Wilkinson and Reed, 2011). In terms of the form, building adaptation can be categorized as in-use adaptation, or refurbishment; and across-use adaptation, or adaptive reuse, or building conversion (Shahi *et al.*, 2020; Wilkinson, 2014a). Due to the rapid development of communities and socio-economic changes, buildings are expected to be adapted during their lifecycle; hence, adaptations need to be facilitated by the building configuration and composition (Ross, 2017). The adaptability of buildings depends on building-related attributes (Stone, 2005) and could moreover be enhanced by amendments in context-related issues – e.g. legislations and market conditions (Remøy and Wilkinson, 2012; Terlikowski, 2017; Wilkinson, 2014c).

The building adaptability concept, also known as “adaptivity” or “adaptive capacity”, has emerged as a quality indicating the capacity of a building to be adapted. Different definitions for adaptability were formulated. Pinder *et al.* (2017) indicated that the majority of adaptability definitions are context-specific and influenced by the aim of delivering a quality – e.g. changeability or meeting future demands. Table 2.2 lists building adaptability-related definitions. Overall, most of the definitions tend to express the ability of a building to accommodate change or keep its functionality, as for example: facilitate physical modifiability (Heidrich *et al.*, 2017; Ross, 2017), keep the building value or usefulness (Eguchi *et al.*, 2011; Geraedts *et al.*, 2017;Hudec and Rollova, 2016), and preserve the physical condition or attributes (Geraedts *et al.*, 2017; Langston, 2014b). Different studies argue the effectiveness of building adaptability as a means to contribute to society, by smoothing the way for regenerating the built environment or bringing vitality to existing premises (Mahtab-uzZaman, 2011; March *et al.*, 2012; Mısırlısoy and Gunçe, 2016; Philokyprou, 2014).

To indicate the embodiment of building adaptability, different studies investigated the changes that could take place in buildings over their service life; thus, captured the way in which adaptability could be configured. Brand’s (1994) concept of “shearing layers” in buildings was amongst the first attempts to capture how adaptability can be configured. The concept describes that building changes occur in physical building layers during different timespans. The “shearing layers” concept divides the building into 6 layers: site, structure, skin, services, space plan, and stuff, indicating that the first layer is the longest and the last is the shortest in terms of the rate of temporal changes. Accordingly, building layers should be independently configured; the longest should be the strongest to create building longevity, whilst the shortest should be the most flexible part, to ensure the space functionality (Brand, 1994).

TABLE 2.2 Building adaptability related definitions

Term	Definition	Implied quality and aim
Building adaptability	*"the inherent properties in a building that gives it the ability to change, or the relative ease with which it can be changed through some external intervention."* (Heidrich *et al.*, 2017)	**Quality:** The ability to accommodate building changes in general. **Aim:** Facilitation of modification
	"the capacity of a building to accommodate effectively the evolving demands of its context, thus maximising value through life." (Eguchi *et al.* 2011)	**Quality:** The ability to meet the future demands. **Aim:** Maximization of value and building longevity.
	"The capacity to be modified for a new purpose." (Hudec and Rollova, 2016)	**Quality:** Ability to accommodate building changes. **Aim:** Facilitation of embodying new function.
	"the ease with which a building can be physically modified, deconstructed, refurbished, reconfigured, expanded, and/or repurposed." (Ross, 2016)	**Quality:** Ability to accommodate building changes. **Aim:** Ease of implementing physical modifications and embodying new function.
	"building's ability to meet shifting demands without physical changes". (Geraedts *et al.*, 2017)	**Quality:** Ability to meet future demands. **Aim:** No physical alteration.
Adaptive reuse potential	"Propensity of an asset to be 'recycled' to perform a significantly different function while keeping the basic attributes of the asset in place.". (Langston, 2014b)	**Quality:** Functional recyclability. **Aim:** Preservation of basic physical features of the building.
Adaptive capacity of building	*"characteristics that enable it to keep its functionality during its technical life cycle in a sustainable and economic profitable way, withstanding changing requirements and circumstances."* (Geraedts *et al.*, 2017)	**Quality:** Ability to preserve building functionality **Aim:** Sustainability, economic profitability, and changeability to future needs and conditions.

As the "shearing layers" concept is oriented to the physical building composition, other design and spatial aspects are apparently overlooked. Thus, different determinants were defined later by various authors. Overall, different terms have been used by authors to articulate adaptability determinants (Manewa *et al.*, 2016), while some determinants overlap in meaning or context (Geraedts *et al.*, 2017).

TABLE 2.3 Building adaptability determinants

Source (Temporal order)	Determinants									
	Flexibility/ Adjustability	Generality/ Multifunctionality/ Versatility	Elasticity/ Expandability/ Scalability	Movability / Relocate-ability	Dismantlability (dismountable/ deconstruct-able)/ Removability	Convertibility/ Transformability	Recyclability/ reusability/ Disaggregatability	Refit-ability	Accessibility/availability	Modularity/regularity
(Arge, 2005)	X	X	X							
(Douglas, 2006)	X		X		X	X	X			
(Beadle *et al.*, 2008)	X	X	X	X	X		X	X		
(Eguchi *et al.*, 2011)	X		X	X			X	X	X	
(Saghafi and Ahmadi, 2011)	X		X		X	X	X			
(Estaji, 2014)	X	X							X	
(Sadafi *et al.*, 2014)	X	X			X	X				
(Hudec, and Rollová, 2016)	X		X	X		X	X			
(Heidrich *et al.* 2017)	X	X	X	X		X		X		
(Manewa *et al.*, 2016)	X	X	X		X	X	X	X		X
(Geraedts *et al.*, 2017)	X		X		X	X				X
(Orłowski *et. al.*, 2017)	X		X		X				X	
(Pinder et al., 2017)	X	X	X	X		X		X		
(Ross, 2017)	X		X		X				X	X
(Kyrö *et al.*, 2019)	X	X	X							
(Bettaieb, and Alsabban, 2021)	X	X	X	X		X				X
Frequency	16	9	14	6	8	9	6	5	4	4

Table 2.3 illustrates 10 common determinants of building adaptability. Overall, these determinants relate to the physical and spatial attributes of buildings, and generally put forward configuration-oriented and active composition and use-oriented design solutions (Milwicz and Pasławski, 2018). Next, these determinants are briefly described as follows:

- **Flexibility/adjustability:** Flexibility – also called adjustability – is the most common determinant of building adaptability (Geraedts *et al.*, 2017). It refers to the possibility to adjust the spatial configuration of the building through minor interventions (Douglas, 2006; Eguchi *et al.*, 2011), and potentially by users within a short period of time (Arge, 2005; Pinder *et al.*, 2017). For instance, the provision of adjustable and movable building products is an example of flexibility (Alhefnawi, 2018; Heidrich *et al.*, 2017; Pizzi *et al.*, 2012; Scuderi, 2019).

- **Generality/multifunctionality/versatility:** Generality – also called multifunctionality or versatility – refers to the possibility of using the spaces in a building for different purposes without conducting any changes (Arge, 2005). The provision of a multi-purpose space (Kyrö *et al.*, 2019), as well as smart technologies and control systems (Unzurrunzaga and Branchi, 2013), are exemplary for generality.

- **Elasticity/expandability/scalability:** Elasticity – also called expandability or scalability – relates to the possibility to increase the volume of the building, vertically or horizontally (Beadle *et al.*, 2008), or divide and merge building spaces (Arge, 2005). Provision of a surplus capacity in the building is an exemplary strategy for expandability (Geraedts *et al.*, 2017), while the provision of an open floor and separation of infills from supports (Capolongo *et al.*, 2016; Meng and Fu, 2017), and adjustable partitions are exemplary strategies for enabling space reconfiguration (Ross, 2017).

- **Movability/relocate-ability:** Movability – also called relocate-ability – relates to the possibility to easily change the location of building assets (Heidrich *et al.*, 2017; Pinder *et al.*, 2017), or displace the building components (Alhefnawi, 2018; Beadle *et al.*, 2008). Movability can be embedded by using demountable and independent products (Eguchi *et al.*, 2011), or relocatable systems (Kyrö *et al.*, 2019). However, this determinant apparently overlaps with flexibility and is a part of it, as it considers configurational changeability.

- **Dismantlability/removability:** Dismantlability – also called dismountable, deconstruct-able, or removability – refers to the possibility of removing physical objects easily and effectively (Douglas, 2006). Dismantlability can be realized by using demountable products as well as prefabricated and standardized components (Sturgis, 2017; Webb *et al.*, 1997). This determinant apparently interrelates with movability, as it considers the mobility of physical objects in buildings.

- **Convertibility/transformability:** Convertibility – also called transformability – relates to the possibility of giving the building a new function in light of physical, legal, and economic constraints (Douglas, 2006; Remøy, 2014b). Hence, this determinant is a context-specific dimension (De Gregorio *et al.*, 2020). Other issues that could influence the building convertibility include architectural, cultural and locational aspects (Aydin, 2010; Dyson *et al.*, 2016; Remøy and van der Voordt, 2014; Yaldiz and Asatekin, 2013). Building conversion can be facilitated by providing a central core for building services (Remøy *et al.*, 2011), modularising and opening the plan configuration, and enabling mixed-use (Raith and Estaji, 2020; Szarejko and Trocka-Leszczynska, 2007; Włodarczyk and Włodarczyk, 2015). Convertibility partially interrelates with generality in terms of providing multifunctionality, but generality refers to the spaces within the building while convertibility refers to the building as a whole.

- **Recyclability/reusability/disaggregatability:** Recyclability – also called reusability or disaggregatability – relates to the possibility of facilitating material reuse and recycling (Douglas, 2006; Eguchi *et al.*, 2011), which can be achieved by using discrete products (Beadle *et al.*, 2008), as well as using standardized building components, and procuring the service of building products (Webb *et al.*, 1997).

- **Refit-ability:** Refit-ability relates to the possibility to manipulate and improve the performance of components and systems (Heidrich *et al.*, 2017; Pinder *et al.*, 2017). Building refit-ability can be achieved through using dismountable products (Eguchi *et al.*, 2011), coordinating the interaction amongst systems, and providing a surplus capacity in the building design (Geraedts *et al.*, 2017).

- **Accessibility/availability:** Accessibility – also called availability – relates to the capacity of accessing the building components and systems, for further reprocessing and changes (Eguchi *et al.*, 2011; Ross, 2017). This can be achieved by providing redundant spaces for technical works, using dismountable products, and coordinating the interaction among technical systems (Orłowski*et al.*, 2017; Sadafi *et al.*, 2009). This determinant overlaps with refit-ability, as both consider adjusting the technical performance besides the provision of redundancy in the technical capacity of the building.

- **Modularity/regularity:** Modularity – also called regularity – refers to the potential of increasing the regularity in the building pattern (Sadafi *et al.*, 2014). Building modularity can be embodied spatially and physically (Geraedts *et al.*, 2017), through modularising the layout of spaces and services (Ladinski, 2017), as well as using unitized and prefabricated building components (Montoliu-Hernández and Rodríguez-Álvarez, 2017).

2.5.2 Circular economy and circularity in buildings

CE is an emerging economic and development paradigm that is aimed at realizing economic prosperity and environmental quality using the principles of the R-strategies such as reduction, reuse, and recycling (Kirchherr *et al.*, 2017). CE applies the R-strategies to avoid waste generation and negative environmental impacts, through creating an entirely closed-reversible resource chain of “loops” (Sanchez and Haas, 2018). Many conceptual frameworks have been synthesized to depict CE, such as the “Butterfly Diagram” (Ellen MacArthur Foundation, 2019). The “Butterfly Diagram” model indicates that technical and biological resources should flow in a closed reversible system through closed-reversible chains, or “value cycles”. Particularly, this framework indicates that all technical resources are reprocessed and restored through R-strategies or operational measures, while biological resources are cyclically regenerated in the system through returning them to nature.

Operationalizing circularity in the built environment has been perceived as a crucial step to reduce resource consumption and eliminate waste generation (Geldermans *et al.*, 2019a). CE operationalisation in buildings has not only been perceived as an environmental protection action (Huuhka and Vestergaard, 2020), but also as a strategy to add value to the built asset (Zimmann *et al.*, 2016). Operationalising circularity in the built environment means that cities should be perceived and strategically operated as urban mines and buildings as material banks, meaning that building products should be processed and utilized in a closed-reversible product chain (Giorgi *et al.*, 2020). The adoption of the cradle-to-cradle concept – integration between lifecycle thinking and quality control – is important for the transition to circularity (Geldermans, 2016). In addition, a multi-level framework that coordinates the three levels, macro, meso and micro, is needed to incorporate circularity in practice (Foster *et al.*, 2020). This implies that circularity in buildings cannot be embodied only through active or passive design solutions, but rather it needs an operational interaction on all societal levels (Cottafava and Ritzen, 2021). In the tactical part, operationalising CE in the built environment is enabled by numerous actions, such as: industrial symbiosis (Ness and Xing, 2017), stakeholder collaboration (Acharya *et al.*, 2018; Valdebenito *et al.*, 2021), provision of a material reuse market (Cai and Waldmann, 2019), adoption of new business models (Acharya *et al.*, 2018; Kaya *et al.*, 2021a), utilisation of enabling technologies (Antonini *et al.*, 2020), and legislative amendments (Tserng *et al.*, 2021; Foster *et al.*, 2020).

Circularity has emerged and gained importance as a new research and sustainability paradigm in the built environment-related literature (Akhimien *et al.*, 2021; Eberhardt *et al.*, 2022). Based on the literature review, four built environment-oriented circularity definitions were found. As shown in Table 2.4, all definitions indicate the capacity to fulfill the loops "closed-reversible chains" for building materials through dynamics in the building configuration and operation. However, the implied aims of the definitions slightly differ upon the context, but overall, they imply efficiently keeping the usefulness of the built asset. All definitions indicate that design and process coordination is a fundamental principle for circularity operationalization in buildings.

TABLE 2.4 Building circularity related definitions

Term	Definition	Implied quality and aim
Circular building (process)	*"The dynamic of associated processes, materials and stakeholders that accommodate circular flows of building materials and products at optimal rates and utilities."* (Geldermans *et al.* 2019b)	**Quality:** Circularity of material flow. **Aim:** Optimal utility "efficient usefulness"
Circular building (object)	*"Is the manifestation of this in a temporary configuration."* (Geldermans *et al.* 2019b) **Note:** this definition refers to the context of the previous definition	**Quality:** Circularity of material flow **Aim:** Optimal utility "efficient usefulness".
Circular economy in buildings	*"A strategic programming of a building to easily change its configuration for longevity and potentially be susceptible to the loop of reduce, reuse and recycle for resource efficiency."* (Akhimien *et al.*, 2021)	**Quality:** Resource reprocessing (restoration) and longevity **Aim:** Configuration changeability.
Circular built environment	*"Circular built environment is that "embeds the principles of a circular economy across all its functions, establishing an urban system that is regenerative, accessible and abundant by design."* (Acharya *et al.* 2018)	**Quality:** Circularity of the economy "system of closed-resource loop". **Aim:** Regenerative and available built environment.

Different studies linked building-related practices to CE-oriented models as an attempt to illustrate how circularity can be operationalized in buildings. For instance, building-related practices could be positioned in ReSOLVE, a framework that is intended to facilitate the transition to CE through industries (Zimmann *et al.*, 2016). Other studies have captured or contextualized research narratives of CE applications in the built environment (Abadi and Sammuneh, 2020; Akhimien *et al.*, 2021; Eberhardt *et al.*, 2022). Based on the integrative literature analysis, Table 2.5 summarizes 10 common circularity determinants in buildings, showing the variety of terms that scholars and practitioners use.

TABLE 2.5 Building circularity determinants

Source (Temporal order)	Determinants									
	Flexibility/ adaptability	Serviceability/ maintainability (operation)	Materiality	Dismantlability/ Disassembly/ (dismountable/ deconstructable) (Material independency)	Exchangeability/ Re-distribution	Recyclability/ Reusability Reversibility (Looping)	Modularity/ regularity / standardization	Re-generativity (material/ energy) / Renewability / Recovery	Virtuality/ / Dematerialisation	Shareability/ Multi-usability
(Geldermans, 2016)	X	X	X	X		X	X	X		
(Zimmann *et al.*, 2016)	X	X	X	X	X	X		X	X	X
(Gravagnuolo *et al.*, 2017)	X	X	X		X	X		X	X	X
(Ness and Xing, 2017)	X	X	X	X	X	X	X	X	X	X
(Acharya *et al.* 2018)			X			X		X		
(Geldermans *et al.* 2019b)	X	X	X	X	X	X	X	X		
(Huovila *et al.*, 2019)	X		X	X		X	X	X		
(Iyer-Raniga, 2019)	X	X	X	X	X	X	X	X	X	X
(Abadi and Sammuneh, 2020)		X		X		X	X			
(Antonini *et al.*, 2020)	X		X	X		X		X		
(Eberhardt *et al.*, 2020)	X		X	X		X	X	X		X
(Kanters, 2020)	X		X	X		X				
(Akhimien *et al.*, 2021)	X	X	X	X	X	X	X			
(Cottafava and Ritzenb, 2021)	X	X	X	X		X		X		
Frequency	12	10	13	12	6	14	8	11	4	5

As shown in Table 2.5, most of the circularity determinants interrelate with the determinants of building adaptability. This indicates that adaptability in buildings is fundamental for operationalizing CE in buildings, agreeing with Geldermans's (2016) argument, indicating that adaptability is an effective means that smoothens the way for the closed-reversible chain. Next, these determinants are briefly described as follows:

- **Flexibility/adaptability:** Flexibility is a key determinant of building circularity, as it supports the dynamics that are associated with the circularity processes (Geldermans *et al.*, 2019b). However, many authors used both terms: adaptability and flexibility. This kind of semantic permutations is possible, as Pinder *et al.* (2017) indicated that there is a misconception in the distinction between the adaptability concept and flexibility as an adaptability component. To incorporate circularity in the built environment, flexibility should be incorporated in the design of new buildings (Geldermans, 2016), as well as in the adaptation of existing buildings (Kaya *et al.*, 2021b). According to the literature, flexible strategies for circular buildings are similar to those mentioned in the building adaptability-related literature (Eberhardt *et al.*, 2022), including design for material independency (shearing layers) and utilisation of moveable components (Geldermans *et al.*, 2019c).

- **Serviceability/maintainability (operation):** Serviceability – also called maintainability – concerns the possibility to operate the built assets, to prolong their lifespan, maximize their utilisation, and thus, reduce the need for consuming energy (Abadi and Sammuneh, 2020) or new materials (Akhimien *et al.*, 2021). Serviceability can be operationalized through repairing and preserving the building assets (Huuhka and Vestergaard, 2020), as well as applying an effective maintenance regime (Iyer-Raniga, 2019; Tserng *et al.*, 2021).

- **Materiality:** As material circularity is a fundamental and rooted principle in the CE paradigm, materiality concerns the entire chain of products in the built environment (Giorgi *et al.*, 2020). In this context, materiality is the determinant that expresses the possibility to facilitate entire processes of selecting, using, managing, storing and reusing/recycling building materials and products (Akhimien *et al.*, 2021; Kanters, 2020). Materiality can be operationalized through: using secondary products instead of new products – to avoid the use of primary resources and raw materials (Foster, 2020), properly storing and managing the materials (Iyer-Raniga, 2019), applying material passports in new and existing buildings – a documentation of specifications of the material used (Huovila *et al.*, 2019; Tserng *et al.*, 2021), and contribute to the construction and waste (C&W) management industry (Cai and Waldmann, 2019; Abadi and Sammuneh, 2020).

- **Dismantlability/disassembly/material independency:** Dismantlability of building components is amongst the key adaptability-related determinants for operationalising circularity in buildings, as it is a means to keep material in the chain (Antonini *et al.*, 2020; Geldermans, 2016). Dismantlability can be achieved through using dismountable products (Kanters, 2020) and standardising the building design and its systems (Akhimien *et al.*, 2021). However, dismantlability in existing buildings could be low, because the majority of them were built using low-dismantlability construction techniques (Cottafava and Ritzen, 2021). In this regard, selective dismantling is a possible strategy (Cai and Waldmann, 2019; Sanchez and Haas, 2018). Selective dismantling is a systematic process of deconstructing and removing building components, part by part, to avoid building collapse or deterioration (Bertino *et al.*, 2021).

- **Exchangeability/re-distribute:** Exchangeability is an operation-oriented determinant, as it refers to the possibility of coordinating the product flow in case of replacement or return. This determinant contributes to keep the physical asset in the closed-reversible chain, to avoid sending building components back to landfills, while enabling asset replacement with more energy-efficient alternatives (Zimmann *et al.*, 2016). This can be achieved in different ways, including: providing a user-centereddesign – e.g. system per user (Geldermans *et al.*, 2019b, c), procuring the service of building products – e.g. performance-based servicing of asset – instead of ownership (Foster, 2020), replacing existing systems with efficient technologies (Iyer-Raniga, 2019). Operational lease contracts are new business models that could facilitate the exchangeability of building material and components (Ploeger *et al.*, 2019).

- **Recyclability/reusability/reversibility (looping):** Recyclability and reusability are keys to keep all the building materials and products in a reversible closed-reversible chain through restoring or reprocessing them (Zimmann *et al.*, 2016). In building design, recyclability can be embodied by using second-hand materials and reusable products (Akhimien *et al.*, 2021; Eberhardt *et al.*, 2022; Geldermans, 2016). For buildings in-use or that are approaching their end of life, recyclability can be operationalized through reusing and recycling material as well as managing C&D (Abadi and Sammuneh, 2020; Foster, 2020; Valitutti and Perricone, 2019). For all buildings, new, in-use or to be demolished, applying material passports is an effective strategy to realize the closed-reversible material loop (Tserng *et al.*, 2021). To some extent, the recyclability determinant overlaps with “materiality”, and seems to be an inherent element in the building materiality.

- **Modularity/regularity/standardization:** Modularity – also called regularity or standardization of design – relates to building adaptability and is often mentioned in the building-circularity-related literature (Akhimien *et al.*, 2021). This is justifiable, as circularity operationalisation in buildings entails an appropriate level of standardisation (Geldermans, 2016). However, the literature indicates that the dimensions of building components need to be configured in a modular pattern and a standardized geometry (Huovila *et al.*, 2019), to facilitate their reuse in other projects (Eberhardt *et al.*, 2022). Prefabrication of components enables for controlling their modularity and quality (Tserng *et al.*, 2021).

- **Re-generativity (material/energy)/renewability/recovery:** Re-generativity of material and energy – also called renewability or recovery – relates to the possibility to regenerate resources, either material or energy, in buildings to safeguard the ecosystem (Acharya *et al.*, 2018; Girard and Vecco, 2021). Re-generativity can be achieved in numerous ways, including the provision of: regenerative design

(Geldermans *et al.*, 2019a), renewable energy systems (Foster and Kreinin, 2020; Sivo *et al.*, 2019), heat storage systems (Dane *et al.*, 2019; Roders *et al.*, 2013), and natural ventilation and lighting (Zimmann *et al.*, 2016).

- **Virtuality/dematerialization:** Virtuality – also called dematerialization – relates to the possibility to reduce the extraction of new material, through digitizing and virtualizing the processes and physical services in buildings (Zimmann *et al.*, 2016). The aim is to reduce the CO_2 emissions that are produced by the embodied energy in the physical assets and operations (Ness and Xing, 2017). Virtuality can be operationalized through adopting smart technologies in the building operation and maintenance (Iyer-Raniga, 2019), besides transferring paper-based operations into online applications (Gravagnuolo *et al.*, 2017).

- **Shareability/multi-usability:** Shareability – also called multi-usability – expresses the possibility of optimally sharing and diversifying building assets. Shareability provides an indication about the utility and efficiency of the asset use (Iyer-Raniga, 2019), and can be achieved by providing: on-demand space (Acharya *et al.*, 2018), multi-purpose space, and shared facilities (Zimmann *et al.*, 2016). Shareability in buildings has been perceived as a strategy that can prolong the life of buildings (Gravagnuolo *et al.*, 2017). Shareability apparently overlaps with the second adaptability determinant "generality", as both indicate the ability of multiple uses of the assets.

2.5.3 Circularity–adaptability interrelationships and contrasts

To summarize, building adaptability indicates the capacity to accommodate change and maintain functionality in buildings in light of changing contextual demands or dynamics. Building adaptability definitions indicate: facilitating physical modification, keeping the usefulness of buildings, and preserving physical building attributes (Table 2.2). Adaptability can be embodied through passive and active solutions that mainly consider physical attributes and spatial configuration of buildings (Tables 2.3). Some determinants overlap with each other, as argued by Geraedts *et al.* (2017) and Manewa *et al.* (2016).

Circularity is still an emerging concept in the built environment. However, building circularity definitions indicate the quality of realizing closed-reversible chains – loops – in the built environment through dynamics in the building configuration and operation. Circularity definitions indicate the aim of efficiently keeping the usefulness of the assets (Table 2.4). As building circularity requires dynamics in the configuration of the physical asset, it relies on half of the adaptability determinants that are related to the physical and spatial attributes (Table 2.5). Figure 2.4 semantically maps the five interrelated determinants of building adaptability and circularity. Figure 2.4 reveals the vital role of building adaptability in facilitating the reversible chain of technical resources, which is in line with the argument of Geldermans (2016). However, circularity is operation-driven and is aimed at creating a well-controlled and closed-reversible product chain, meaning that it relies on operational interventions that could coordinate the supply, use, and reversible flow of assets.

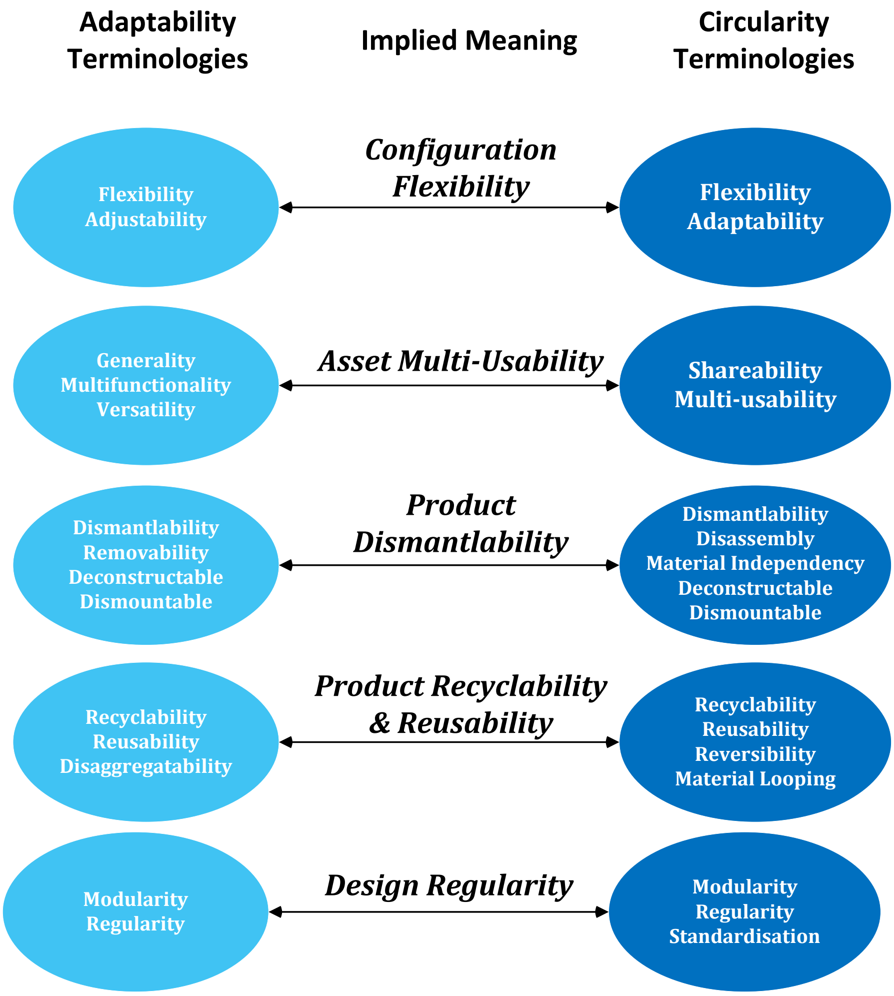

FIG. 2.4 Semantic mapping of the 5 interrelated determinants between building adaptability and circularity

Figure 2.5 presents the interrelationship between circularity and adaptability in buildings, with directly or partially overlapping determinants. For instance, refit-ability and accessibility/availability overlap, as both refer to the technical ability to provide further upgrade to the performance (Heidrich *et al.*, 2017; Ross, 2017). In addition, movability is an inherent aspect in flexibility, as providing a flexible space requires providing movable and demountable products (Geldermans *et al.*, 2019b; Scuderi, 2019). In building circularity, the reusability and recyclability of building products is a prerequisite aspect that is rooted in materiality (Akhimien *et al.*, 2021), where materiality also comprises the reversible chain that facilitates product redistribution (Antonini *et al.*, 2020; Cai and Waldmann, 2019).

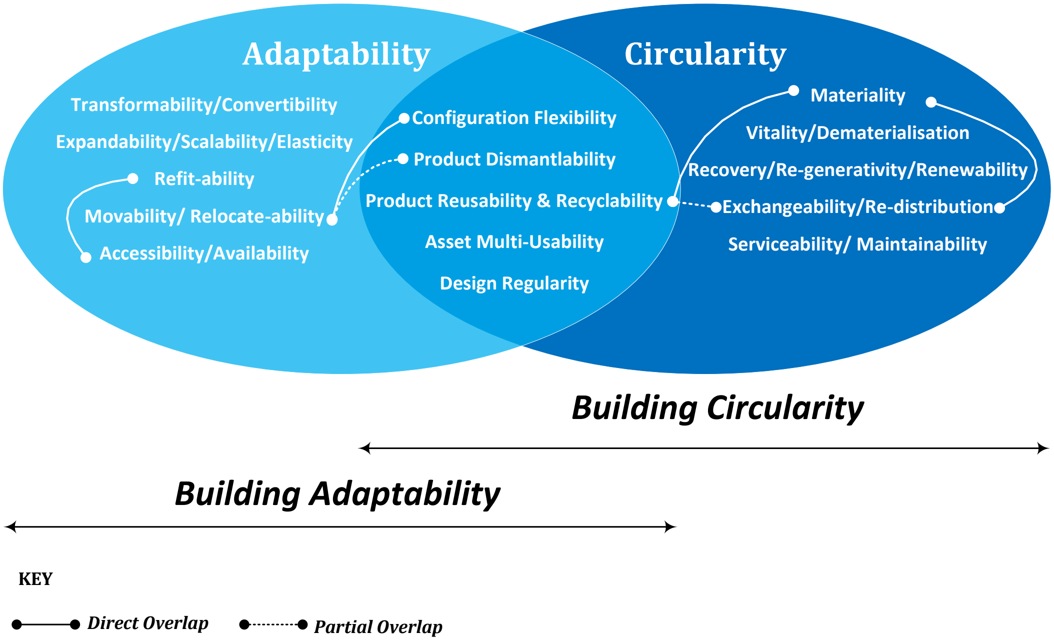

FIG. 2.5 Circularity– adaptability interrelationship in buildings

To recap, both adaptability and circularity consider the ability to enhance dynamic building use. Adaptability considers this capacity from the perspective of building changeability and functionality. Circularity considers it from the view of how to fulfill resource efficiency and reversibility within a closed-reversible value chain. Circularity operationalisation in buildings immediately relies on adaptability-driven solutions, besides operational measures. Overall, both concepts share the aim of keeping the usefulness of buildings.

2.5.4 Circular building adaptability

Based on the analysis, the following definition was formulated: *Circular building adaptability* is 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.

Prefixes were added to the determinants of circular building adaptability to clearly indicate the embodied characteristics. Hence, circular building adaptability can be defined by 10 determinants (Figure 2.6), namely: the configuration flexibility, product dismantlability, asset multi-usability, design regularity, functional convertibility, material reversibility, building maintainability, resource recovery, volume scalability, and asset refit-ability.

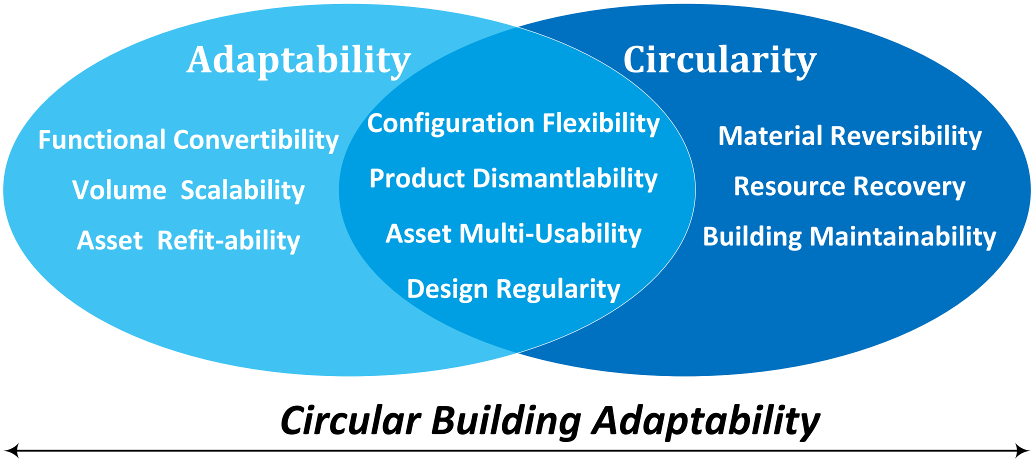

FIG. 2.6 Determinants of circular building adaptability

Next, brief descriptions of the circular building adaptability determinants and their strategies are presented as follows:

- **Configuration flexibility:** Configuration flexibility is the possibility to reconfigure the space layout without neither using external resources nor generating waste (Eberhardt *et al.*, 2022). This can be achieved by using demountable and movable components (Geldermans *et al.*, 2019c).

- **Product dismantlability:** Product dismantlability is the possibility to demount building components without causing damage or waste, to facilitate their use within the building or in another building (Bertino *et al*., 2021). The use of demountable products and design standardization are proactive strategies for designing dismantlable buildings (Geldermans, 2016). Selective dismantling is a possible strategy for dismantlability incorporation while adapting existing buildings (Sanchez and Haas, 2018).

- **Asset multi-usability:** Asset multi-usability is the possibility to create multiplicity in the use of building assets, to maximize their efficiency (Zimmann *et al*., 2016). This can be achieved through the provision and management of multi-purpose spaces (Acharya *et al*., 2018), and shared facilities (Foster, 2020).

- **Design regularity:** Design regularity is the possibility to provide a regular pattern in the spatial configuration and physical composition of buildings (Sadafi *et al*., 2014), to facilitate the possibility of reusing or remanufacturing assets (Eberhardt *et al*., 2022). This can be achieved through providing modular layout and standardized components (Tserng *et al*., 2021).

- **Functional convertibility:** Functional convertibility is the possibility to refunction the building or part of it (Heidrich *et al*., 2017), while keeping its value and prolonging its lifespan (Valitutti and Perricone, 2019). This can be achieved by providing: a modular and mixed-use design (Iyer-Raniga, 2019), and a central core for the building services (Remøy *et al*., 2011).

- **Material reversibility:** Material reversibility is the possibility to provide, use, and reuse building material as efficiently as possible in a reversible value chain (Akhimien *et al*., 2021). This can be achieved by using secondary material, applying material passports, and sending back discarded material to the C&W industry (Abadi and Sammuneh, 2020).

- **Building maintainability:** Building maintainability is the possibility to prolong the usefulness of the building and sustain its performance (Abadi and Sammuneh, 2020). This can be achieved by using smart technologies in the operation (Iyer-Raniga, 2019), conducting proactive maintenance (Gravagnuolo *et al*., 2017), and procuring the service of building components (Foster, 2020).

- **Resource recovery:** Resource recovery is the possibility to regenerate the resources consumed in the building, to reduce the use of new material and energy (Acharya *et al*., 2018). This can be achieved by using renewable energy techniques and facilitating the use of natural ventilation and lighting (Zimmann *et al*., 2016).

- **Volume scalability:** Volume scalability is the possibility to increase or reduce the size of the building or its spaces according to user or organizational demand – to avoid spatial shortage and redundancy (Beadle *et al.*, 2008), while eliminating waste generation (Zimmann *et al.*, 2016). This can be achieved by providing surplus capacity in the design – through over-dimensioning – to allow for upgrade (Geldermans, 2016), while using adjustable and dismantlable components for allowing reducing the capacity of systems or spaces (Huovila *et al.*, 2019). Procurement of building products and components could be a possible strategy to enable the implementation of such changes (Ploeger *et al.*, 2019).

- **Asset refit-ability:** Asset refit-ability is the possibility of providing state-of-the-art products and technologies in the building (Heidrich *et al.*, 2017), while eliminating waste generation or over-investment (Zimmann *et al.*, 2016). This can be achieved by procuring the service of building assets – including components, products, and systems (Ploeger *et al.*, 2019).

2.6 Discussion

Building adaptation is a wide term that is used to express the alteration works that are implemented in existing premises to change their performance, condition, or function in response to building-related, internal, or external triggers. The possibility to adapt buildings is generally known as “building adaptability”, and could apply to in-use or across-use adaptations and ranging from minor to major changes. Building adaptability could be defined by 10 interrelated determinants referring to the physical composition and configuration of buildings. Building adaptability can be embodied proactively or reactively by numerous passive and active design strategies.

Circularity in buildings has emerged as a new sustainability paradigm that is aimed at realizing closed and reversible resource chains, using the principles of the R-strategies. The operationalization of circularity in buildings relies on half of the adaptability determinants that could facilitate the reversibility of the assets in the chain, besides other process-oriented determinants. This implies that building circularity includes passive, active, and operational strategies. Exemplary strategies for these three types of strategies are: standardizing the building layout, providing moveable building components, and procuring the service of building systems instead of ownership, respectively.

According to the integrative analysis, both qualities – adaptability and circularity – share the aim of prolonging the asset usefulness and require dynamics in the building configuration and composition. Adaptability perceives that prerequisite from the perspective of facilitating the building alteration, while circularity perceives it from the perspective of achieving the reversibility and efficient flow of building assets within the closed-reversible value chain. Therefore, the integrated synergy between both qualities could facilitate the resilience of buildings to meet future demands while adding value to the built assets without generating waste.

Based on the integrative analysis, circular building adaptability can be defined by 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. The integrative analysis points out that the operationalization of circular building adaptability is not only dependent on passive and active design solutions, but also on process-oriented interventions.

2.7 Conclusion and recommendations

Adaptability is an inherent quality in the operationalization of building circularity, as it can physically facilitate the reversibility of materials in the reversible value chain. However, its positioning in circularity models could overlook some aspects that contribute to long-lasting building functionality. Accordingly, this chapter focused on reconceptualizing building adaptability to incorporate circularity for resource efficiency while contributing to the long-lasting building functionality.

An integrative literature review, using a systematic search process, was conducted. Definitions of circularity and adaptability were critically reviewed, to define the implied qualities and aims in both concepts. Two matrices were developed to identify the determinants of circularity and adaptability. Accordingly, definition, determinants, and strategies of circular building adaptability were defined and synthesized. The following was concluded:

- Adaptability and circularity consider the ability to cope with dynamics of the built environment. Adaptability considers building changeability and functionality in light of contextual dynamic, while circularity considers resource efficiency and reversibility within a closed-reversible value chain – loops.

- Overall, both concepts share the aim of keeping the usefulness of buildings. Adaptability determinants are related to passive and active design solutions aimed at facilitating the physical and spatial dynamics. Circularity operationalization in buildings relies on half of the adaptability determinants besides process-oriented interventions to control the supply, use, and reversible chain of resources.

- Circular building adaptability can be operationalized through applying 10 circularity- and adaptability-related determinants, comprising design- and operation-oriented strategies, namely: configuration flexibility, product dismantlability, asset multi-usability, design regularity, functional convertibility, material reversibility, building maintainability, resource recovery, volume scalability, and asset refit-ability.

- This chapter concludes that considering and implementing the circularity and adaptability determinants, proactively or reactively, would simultaneously create numerous benefits, namely: embodying the adaptive responsiveness in buildings to withstand contextual dynamics, creating value for the building assets, and reducing waste generation and environmental degradation resulting from buildings.

The outcomes of this chapter are theoretical and limited to a reconceptualization of interrelated concepts based on an integrative literature analysis. Thus, the recommendations of this chapter are threefold. First, development of a practical and evidence-based framework for circular building adaptability would be needed to provide an empirically validated methodological tool. Such a framework would be useful for practitioners to proactively or reactively operationalize circular building adaptability. Second, operational research is needed to test the applicability and facilitate the operationalization of circular building adaptability in a pragmatic way. This kind of research would lay the ground for regulating and operationalizing the development of circular and adaptable buildings. Third, within the context of operationalizing the proposed concept and framework, the legislative dimension needs to be considered, as laws and regulations can play a vital role in this process.

TOC

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3 Circular building adaptability in adaptive reuse: Multiple case studies in the Netherlands

3.1 Overview of chapter 3

Chapter 2 presented a theoretical conceptualization of circular building adaptability – which is a synthesized reconceptualization that brings the principles of circularity and adaptability together. Chapter 2 defined circular building adaptability (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 is expressed with 10 determinants.

This chapter answers the second research sub-question: What are the applicable circularity and adaptability strategies in adaptive reuse projects and their enablers and inhibitors? It expands this theoretical reconceptualization with empirical evidence of the applicable strategies for promoting CBA in adaptive reuse projects including their enablers and inhibitors, by following a multiple-case research approach (Yin, 2009). Figure 3.1 illustrates the interconnection between this chapter and the conceptual scheme of this study.

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This chapter includes additional photos and diagrams to enrich its content with more visuals. The word “chapter” is used instead of “paper”. All headings, figures, and tables are renumbered on the basis of the chapter number. The title of the methodology section is rephrased to be in line with the content of the chapter

3.2 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 chapter 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 findings indicate 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 organizational motivation were frequently observed as 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 chapter 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

Chapter type: Case study chapter

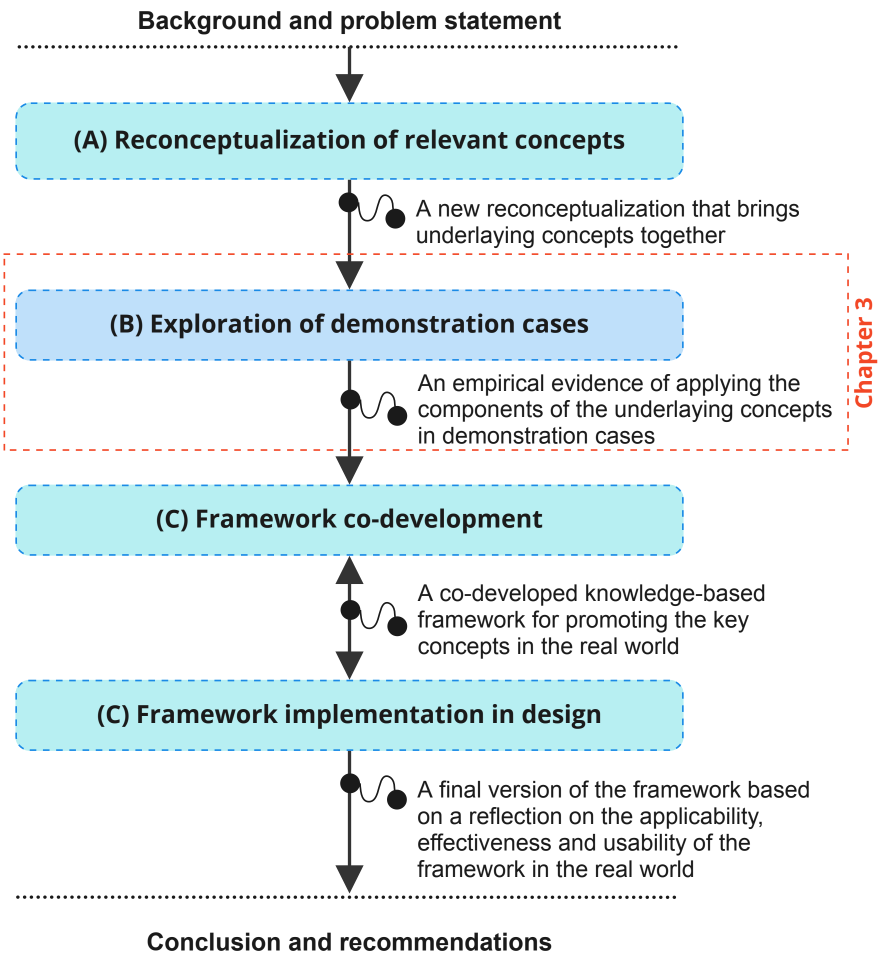

FIG. 3.1 The interconnection between Chapter 3 and the conceptual scheme of this study

3.3 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, operationalizing the circular economy (CE) in the built environment is 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 operationalizing 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.

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This chapter explores the application of CBA-strategies in adaptive reuse projects, in addition to what enables and hinders the implementation of these strategies. Five demonstration circular adaptive reuse projects in the Netherlands were investigated. The investigated case studies in this chapter provide 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. Theory-wise, the results can 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.

3.4 Theoretical background

3.4.1 CBA and its determinants and strategies

Based on the reviewed literature in Chapter 2, CBA has been defined 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 with ten 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”. Table 3.1 lists a brief description of these determinants. It is worth noting that some of the CBA determinants are interrelated; thus, some strategies could contribute to operationalizing more than one determinant (Hamida *et al.*, 2023).

TABLE 3.1 A brief description of the CBA determinants

Determinant	Brief description
Configuration flexibility	The capacity to reconfigure the layout of spaces without utilizing 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 maximizing the efficiency of their utilization
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 y 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, utilize 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 organization, 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.

Note: Adapted from Chapter 2 Hamida et al. (2023)

These determinants can be incorporated into buildings through active, passive, or operational strategies (Table 3.2). Most of the determinants can be promoted by passive strategies. Modularizing and standardizing 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 3.2). For instance, selective dismantling is a reactive strategy 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).

TABLE 3.2 CBA strategies and their corresponding 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		
	Design standardization*	Utilization of adjustable building components**	Utilization of dismountable products**	Utilization of dismountable products**	Design standardization*	Provision of multi-purpose space*	Provision of sharable facilities***	Modularization of spatial configuration*	Utilization of standardized products*	Provision of a core for building services*	Modularization of the building configuration*	Design for a mixed-use (multifunctional) *
(Webb *et al.*, 1997)	X		X	X	X			X	X			
(Arge, 2005)	X	X				X					X	X
(Beadle *et al.*, 2008)	X			X	X	X		X	X	X		X
(Eguchi *et al.*, 2011)	X		X	X	X							
(Geldermans, 2016)	X			X	X				X			
(Manewa *et al.*, 2016)		X		X						X	X	
(Zimmann *et al.*, 2016)				X		X	X			X		
(Heidrich *et al.*, 2017)		X										
(Ness and Xing, 2017)				X		X	X					
(Pinder *et al.*, 2017)	X	X		X				X		X		
(Acharya *et al.*, 2018)						X						
(Cai and Waldmann, 2019)												
(Iyer-Raniga, 2019)							X					
(Kyrö *et al.*, 2019)						X				X	X	X
(Foster, 2020)				X		X	X					
(Kanters, 2020)												
(Ness and Xing, 2017)				X		X	X					
(Pinder *et al.*, 2017)	X	X		X				X		X		
(Acharya *et al.*, 2018)						X						
(Cai and Waldmann, 2019)												
(Iyer-Raniga, 2019)							X					
(Kyrö *et al.*, 2019)						X				X	X	X
(Foster, 2020)				X		X	X					
(Kanters, 2020)												

	(D6) Material reversibility					(D7) Building maintain-ability		(D8) Resource recovery		(D9) Volume scalability		(D10) Asset Refitability		
	Utilization of secondary (reused/ recycled) material*	Utilization 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***	Utilization of renewable energy technology**	Enabling the use of nature (passive) ventilation/lighting**	Design for surplus capacity*	Utilization of movable building components**	Dematerialize the processes***	Utilization of dismountable products**	Procure the service of building products***
	X	X		X		X							X	X
							X							
	X	X											X	
	X									X	X		X	
	X	X								X				
											X			
	X	X	X				X	X	X			X	X	X
	X	X										X		X
										X			X	
	X						X	X				x		
	X	X	X		X									
	X	X	X	X		X		X	X			X		
										X				
	X		X	X	X	X	X	X	X					
	X	X	X											
	X	X										X		X
										X			X	
	X						X	X				x		
	X	X	X		X									
	X	X	X	X		X		X	X			X		
										X				
	X		X	X	X	X	X	X	X					
	X	X	X											

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TABLE 3.2 CBA strategies and their corresponding determinants

Source (Temporal order)	Strategies and their corresponding determinants											
	(D1) Configuration flexibility			(D2) Product dismantlability		D3 Asset multiusability		(D4) Design regularity		(D5) Functional convertibility		
	Design standardization*	Utilization of adjustable building components**	Utilization of dismountable products**	Utilization of dismountable products**	Design standardization*	Provision of multi-purpose space*	Provision of sharable facilities***	Modularization of spatial configuration*	Utilization of standardized products*	Provision of a core for building services*	Modularization of the building configuration*	Design for a mixed-use (multifunctional) *
(Akhimien *et al.*, 2021)			X	X	X							
(Bettaieb and Alsabban, 2021)	X	X				X		X				X
(Cottafava and Ritzen, 2021)				X								
(Tserng *et al.*, 2021)	X						X	X	X			
(Eberhardt *et al.*, 2022)	X			X				X	X			
Frequency	9	5	3	12	5	8	5	6	5	5	3	4

*Note: * Passive strategy; ** Active strategy; *** Operational strategy*

	(D6) Material reversibility					(D7) Building maintain-ability		(D8) Resource recovery		(D9) Volume scalability		(D10) Asset Refitability		
	Utilization of secondary (reused/ recycled) material*	Utilization 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***	Utilization of renewable energy technology**	Enabling the use of nature (passive) ventilation/lighting**	Design for surplus capacity*	Utilization of movable building components**	Dematerialize the processes***	Utilization of dismountable products**	Procure the service of building products***
	X	X	X		X	X	X							
											X			
	X		X											
	X		X	X		X	X	X	X			X	X	X
	X	X												
	15	10	8	4	3	5	6	5	4	4	3	5	6	4

3.4.2 Enabling factors for the CBA strategies

Enabling and inhibiting factors of CBA are context-specific and could be interrelated and changeable (Acharya *et al.*, 2018; Heidrich *et al.*, 2017). Table 3.3 presents six identified enabling factors from the reviewed literature. These enabling factors were identified from the literature reviewed in Chapter 2, based on relevant enablers observed in relation to the presented strategies in sub-subsection 3.4.1.

TABLE 3.3 Potential enabling factors for 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, Pintossi, *et al.*, 2021)			X	X	X	
Frequency	5	5	8	6	6	6

Following is a brief description of the six enabling factors:

- **Industrial symbiosis:** Operationalizing 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).

- **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 asset reversibility but also the maintainability of products that are provided as a service (Kanters, 2020).

- **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 operationalizing CBE (Cottafava and Ritzen, 2021; Giorgi *et al.*, 2020; Kaya *et al.*, 2021b).

- **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 operationalizing CBE but also help to achieve other targets such as value creation and human-oriented development (Ness and Xing, 2017). Collaboration among stakeholders is key to achieving material reversibility, as material looping could not be realized without the effective collaboration of all actors (Iyer-Raniga, 2019). Developing strategic partnerships would contribute to further enhance collaboration (Giorgi *et al.*, 2020; Kaya *et al.*, 2021b).

- **Construction/design innovations:** Innovative design and construction are needed to reactively or proactively operationalize 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 realized (Iyer-Raniga, 2019; Kanters, 2020).

- **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 operations, the provision of renewable energy systems (Acharya *et al.*, 2018), and the use of virtual resources (Iyer-Raniga, 2019). Enabling technologies, such as integrated smart services, can contribute to maximizing the use of natural lighting and ventilation (Zimmann *et al.*, 2016)

3.4.3 Inhibiting factors for the CBA strategies

Recall in sub-subsection 3.4.2 that inhibiting factors of CBA are context-specific, interrelated, and changeable, similar to the enabling factors (Acharya *et al.*, 2018; Heidrich *et al.*, 2017). Table 3.4 presents six identified inhibiting factors for CBA based on the reviewed literature. These inhibiting factors were identified from the literature reviewed in Chapter 2, based on relevant barriers and challenges observed in relation to the presented strategies in sub-subsection 3.4.1.

TABLE 3.4 Potential inhibiting factors for 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

Following is a brief description of the six inhibiting factors:

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- **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).

- **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 operations (Akhimien *et al.*, 2021), installation and reuse of reusable products (Iyer-Raniga, 2019), and use of sustainable material (Cottafava and Ritzen, 2021).

- **Economic constraints (e.g. 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 labor cost (Kanters, 2020). Financial constraints could hinder material reuse and DfD (Kanters, 2020).

- **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).

- **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).

- **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).

3.5 Practice exploration methodology: A multiple-case research approach

This chapter 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 to explore an emerging concept in the built environment (Conejos, 2013).

The followed case study approach in this chapter 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 chapter, 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.

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3.5.1 Defining the research case, its context and boundaries, and selection criteria

In this chapter, the research case and its context and boundaries are defined as follows:

A Research case: The phenomenon of interest

The phenomenon of interest in this chapter 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.

B Contexts and boundaries of the case

According to Yin (2009), boundaries between a phenomenon and its context are 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 chapter, 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, expanding theoretically conceptualized models.

Defining the case boundary – in terms of social, organizational 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.

C Selection criteria

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

- **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.* (2023) were considered as a theory-driven criterion for selecting the cases (see subsection 3.4.1). 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) emphasized the necessity of adopting theoretical propositions in case study research to analytically generalize the findings; thereby, expanding the existing body of knowledge.

- **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).

- **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.

- **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 chapter, the involvement of qualified participants relied on their qualifications 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 generalization, owing to the potential duplication of the findings and replication of different patterns across a heterogeneous sample (Yin, 2009).

3.5.2 Data collection methods

The case study research uses multiple sources of evidence to uphold its construct validity (Yin, 2009). This chapter applies a stepwise data collection process in each case, using archival research and in-depth interviews, respectively (Figure 3.2).

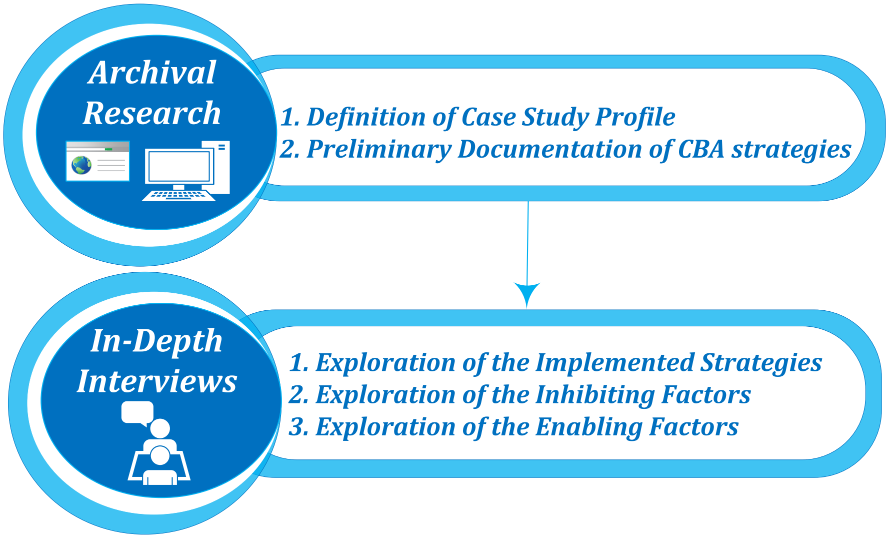

FIG. 3.2 Data collection methods used in the case studies

A 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 chapter, 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.

B 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 (Appendix A), 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 (see Appendix A).

In the key part, the questions covered the applied CBA strategies and their enabling and inhibiting factors 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 ensure the inclusion of representatives of the concept adopters who played a key role in the decisions made on the strategies and the implementation of their solutions. Table 3.5 presents the profile of the conducted interviews in the case studies.

TABLE 3.5 Profile of the conducted interviews in the case studies

Case	Interviewee role in the project	Qualification	Experience	Time of interview	Method
Case study 1 (C1)	Project developer	Architect (MSc in Architecture and MSc in Real Estate and Housing)	CEO of the organization	1:59:03	Face-to-face
Case study 2 (C2)					
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 organization	2:16:57	Face-to-face*
Case study 5 (C5)	Project leader	Architect	Chair of the organization	1:22:50	Face-to-face**

** The interviewee asked a close colleague to join the interviewee to translate and interpret some questions and answers*

***The interviewee asked a close colleague to join the interview to add further clarifications*

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 organization. The interviewed expert from C4 asked a close colleague to join the interview to translate and interpret some questions and answers, also the interviewee from C5 asked a close colleague to join the interview to add further clarifications. The interviews lasted from 1 h 22 min to 2 h 16 min. All interviews were recorded and transcribed.

3.5.3 Description of the selected cases

The selected cases met the selection criteria as shown in Table 3.6.

TABLE 3.6 Mapping the selected cases to the set selection criteria

Criteria	Cases				
	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 center	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

Following is a brief description of these case studies:

- **Case 1 (C1) – Transformation of a vacant office building to mixed-residential use in Den Haag:** This adaptive reuse project was implemented to revitalize 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.

- **Case 2 (C2) – Transformation of obsolete and vacant office buildings into a care center in Harderwijk:** This adaptive reuse project was implemented to convert three obsolete and vacant office buildings into a care center. 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.

- **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.

- **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 underutilized gym to an office building while experimenting with circularity in building transformation. The applied CBA-related strategies comprise installing solar panels, using secondary materials, integrating and standardizing different systems in the composition of wall panels, and using lightweight materials.

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- **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.

3.5.4 Data analysis, interpretation, and triangulation

Inductive and deductive – data-driven and theory-driven – procedures were, respectively, used to analyze 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 the present study in this chapter 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 analyze the data, within each case and then across the cases. This kind of procedure is useful to anticipate and structure the data patterns, using theoretically conceptualized frameworks to code and analyze 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 analyzed, using the defined CBA determinants by Hamida *et al.* (2023) to structurally guide the analysis of the strategies. Similarly, the explored enabling and inhibiting factors were analyzed against the revised literature (see sub-subsections 3.3.2 and 3.4.3).

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 sources (Flick, 2004). The use of existing theory as a secondary source to corroborate empirical evidence is a triangulation approach in qualitative research (Creswell, 2013).

3.6 Findings

3.6.1 CBA 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 3.7).

D1 – Configuration flexibility

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 standardized 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 afterward (Figure 3.3). Additionally, the floor plan of the new use was deliberately kept open.

TABLE 3.7 Mapping the cases with the defined ten determinants of CBA by Hamida *et al.* (2023)

CBA Determinant	CBA Strategy	Cases				
		(C1)	(C2)	(C3)	(C4)	(C5)
Configuration Flexibility (D1)	Use of standardized 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 standardized building products	X	X	N/A	X	N/A
	Standardization of the layout of spaces (modularization)	X	X			
Functional Convertibility (D5)	Design for multi-functionality	X	X	N/A	N/A	N/A
	Design for surplus capacity	X	X			
	Decentralization of design	X	X			
	Modularization 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			
	Decentralization of design	X	X			

** Applied in 7 towers out of 10 towers (the mixed-use towers)*

*** Applied in 3 towers out of 10 towers (the school project)*

N/A: Not applied

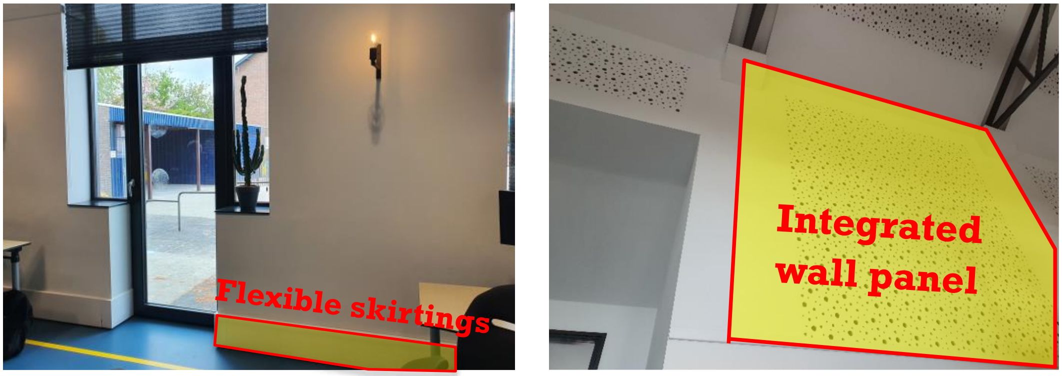

FIG. 3.3 Configuration flexibility-oriented solutions implemented in C4
Source: Photos taken by the author

D2 – Product dismantlability

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 as shown in Figure 3.3. Overall, these findings corroborate literature that emphasizes the role of DfD as a requirement for a circular product chain (Akhimien *et al.*, 2021; Geldermans, 2016).

D3 – Asset multi-usability

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 realized 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).

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D4 – Design regularity

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 standardized building products was a common strategy for design regularity in these cases. The interior partitions were standardized by providing unitized walls. In C1 and C2, the layout of the interior partitions was modularized. In C5, the layout of the walls was modularized, following the modularity of the original design. These solutions are mentioned in the literature as strategies for building circularity and adaptability (Eberhardt *et al.*, 2022).

D5 – Functional convertibility

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 decentralization and design modularization. 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. Figure 3.4 illustrates how the design for functional convertibility was promoted in C1 and C2 by the principles the shearing layers concept by Brand (1994).

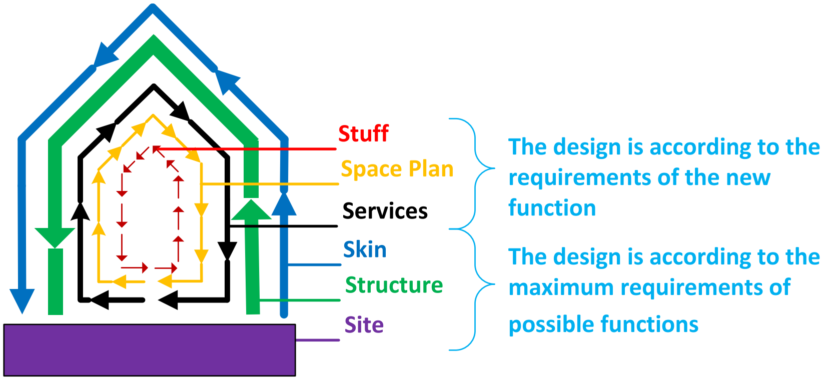

FIG. 3.4 Design for functional convertibility in C1 and C2 using the shearing layers concept by Brand (1994)

Decentralizing 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 modularized and aligned with the possible functions, using unitized building products.

D6 – Material reversibility

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

D7 – Building maintainability

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.

D8 – Resource recovery

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 have enabled for generating an extra amount of energy exceeding the building demand, which facilitated supplying other uses. Installing such systems to realize 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).

D9 – Volume scalability

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 afterward. 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 afterward.

D10 – Asset refit-ability

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 (Figure 3.4). This strategy is common for meeting future demands (Arge, 2005; Kyrö *et al.*, 2019), as well as operationalizing material circularity (Geldermans, 2016). In both cases, decentralizing the design, through the independence of building systems and their shafts, enables for adding new systems or features afterward. 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.

3.6.2 Enabling factors for the CBA strategies

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

- **The building characteristics:** This factor relates to the size, configuration, and physical and spatial building features. 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 soundproofing 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 design decentralization and the design for surplus capacity. In C5, the modularity of the floor plan facilitated providing standardized partitions and second-hand plumbing fixtures. This enabler was found in the adaptability and circularity relevant literature (Cottafava and Ritzen, 2021; Kamara *et al.*, 2020).

- **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 in determining the applicable strategies. In C1, the partnership facilitated the façade leasing. These findings corroborated discussions available in the relevant literature (Acharya *et al.*, 2018; Kanters, 2020).

- **The presence of a motivated and capable team:** The existence of a shared aim for operationalizing 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 to reflect creativity in practice facilitated the implementation of circularity in adaptive reuse, which agrees with relevant literature (Kanters, 2020; Kaya *et al.*, 2021b).

- **The economic viability of basic circular strategies:** The low cost of reusing old products motivates operationalizing 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.

3.6.3 Inhibiting factors for the CBA strategies

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

- **Lack of expertise:** In C5, the interviewee indicated that hiring circularity expertise was costly for a single transformation project. This finding agrees with Kanters's (2020) findings 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.

- **Technical complexities with building products and materials:** 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.

- **Economic infeasibility of innovative/advanced strategies:** Although the low-cost of reusing existing building components enables 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 specialized carpenter to reassemble the doors, totaling 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.

- **Organizations and practitioners tend to follow traditional paradigms:** The interviewees from C1, C2, and C3 indicated that many organizations 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-centered system was impeded by the client resistance to change. These findings agree with Kanters (2020) who pointed out that market conservativeness is an obstacle to building circularity.

- **Lack of data and warranty on old material:** In C3, C4, and C5, the lack of records on building materials 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.

- **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).

3.7 Discussion and reflections

The presented exploratory study in this chapter 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 operationalized 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 3.7), three determinants were operationalized in all cases, two barely operationalized in two cases while the other five determinants were operationalized at various levels as follows:

- 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.*, 2023).

- 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).

- 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).

3.8 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, and also for fulfilling long- and short-term benefits, such as long-lasting building functionality and value addition.

This chapter 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 organizational 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 the presented study in this chapter 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 limitation 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 programs to include guidelines for CE in adaptive reuse. More specifically, this chapter 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 realized 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 legislation should be amended to promote implementing CBA strategies in adaptive reuse projects.

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4 A Co-Developed framework towards promoting circular building adaptability in adaptive reuse (CBA-AR)

4.1 Overview of chapter 4

Chapter 3 expanded the theoretical reconceptualization of CBA based on lessons learned from adaptive reuse projects that manifest components of circularity and adaptability. This chapter answers the third research sub-question: What strategies and factors should be considered for circular and adaptable adaptive reuse? It bridges the gap between the knowledge from theory and practice in Chapter 2 and Chapter 3, respectively, by using a participatory approach to co-develop a framework for CBA in adaptive reuse projects – CBA-AR framework. Figure 4.1 illustrates the interconnection between this chapter and the conceptual scheme of this study.

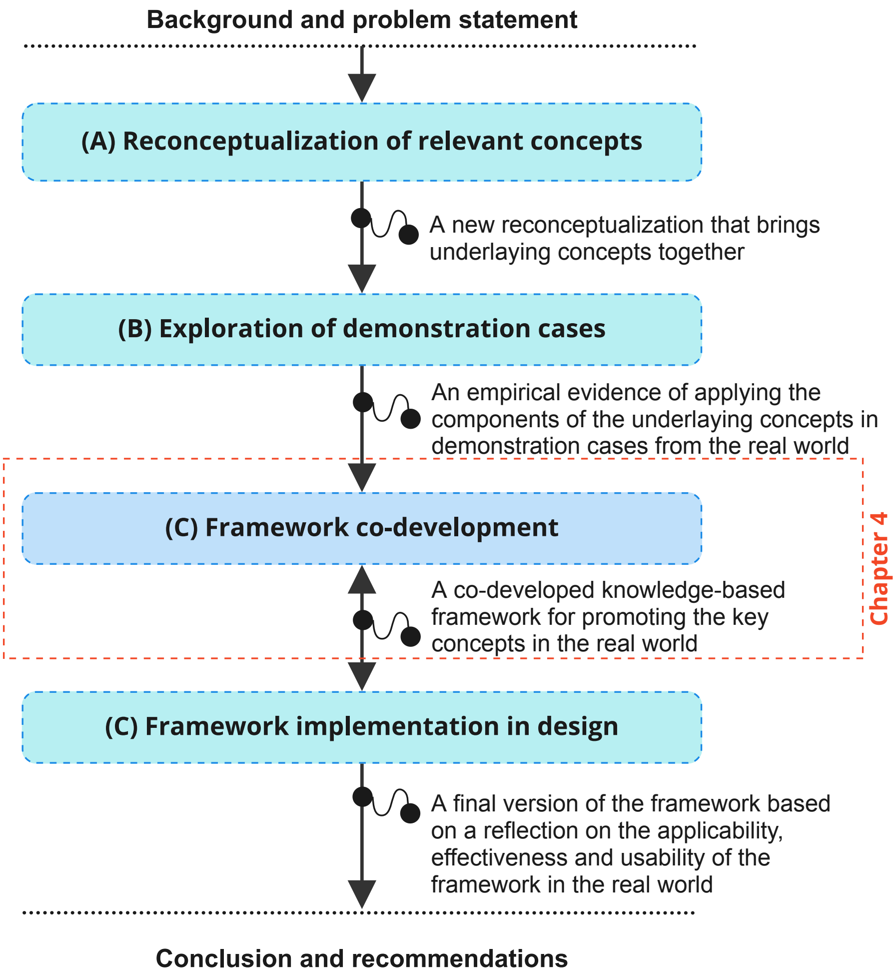

FIG. 4.1 The interconnection between Chapter 4 and the conceptual scheme of this study

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In this chapter, all headings, figures, and tables are renumbered based on the chapter number. The title of the methodology section is rephrased to be in line with the content of the chapter.

4.2 Abstract

Purpose – Circular building adaptability (CBA) in adaptive reuse – building transformation – projects can facilitate a resource-efficient and futureproof redevelopment of the built environment. However, there has been a lack of practical tools that guide practitioners on how to foster CBA in adaptive reuse. Therefore, this chapter aims to collaboratively develop a guiding framework for CBA in adaptive reuse (CBA-AR) projects in general. The CBA-AR framework is a descriptive and content-oriented synthesis mapping a series of strategies to the CBA determinants alongside their enablers and inhibitors

Design/methodology/approach – A participatory research-oriented approach was followed. First, archival research was conducted to develop the CBA-AR framework based on literature review and case studies (see Chapter 2 and Chapter 3). Second, two co-creation workshops, triangulated with structured interviews, were conducted to validate and expand the framework.

Findings – The first version of the CBA-AR framework comprises 30 CBA strategies. It also brings seven enablers and six inhibitors together with the 30 CBA strategies. The outcomes of the participatory approach contributed to refining and expanding the framework. The final of the CBA-AR framework version comprises CBA 33 strategies. This version brings 10 enablers and 7 inhibitors together with the 33 strategies.

Practical implications – This framework can be used as a guiding and reporting instrument by designers and property developers while transforming vacant or obsolete properties in the Netherlands. Policy makers can refer to this framework and amend adaptive reuse legislation.

Originality/value – The CBA-AR framework can introduce a transformative change in theory and practice, as it is based on theoretical, empirical, and participatory research.

Keywords: Adaptability, Adaptive reuse, Built environment, Circularity, Co-creation, Participatory research

Chapter type: Research chapter

4.3 Introduction

The building sector in Europe is perceived as a major contributor to different problems, including climate change, waste generation and high energy consumption. It has been estimated that the existing building stock in Europe consumes about 40% of the operational energy while producing 36% of the total greenhouse gas emissions which are associated with construction, use, renovation and demolition activities (European Commission, 2020). Accordingly, it constitutes an arena for operationalizing new concepts and transformative frameworks in reality to cope with these dilemmas, such as speeding up the transition to circular economy (CE) (Zimmann *et al.*, 2016). In the building sector, adaptive reuse, also known as building transformation, is a multidimensional means to eliminate waste, cope with underutilized property and speed up the transition to CE (Foster, 2020). From an urban regeneration perspective, adaptive reuse is also effective for the redevelopment and revitalization of abandoned areas (Aigwi *et al.*, 2022). Population growth, market dynamics and technological advancement are ongoing triggers for building adaptation (Ross, 2017). In the Netherlands for instance, many canal houses have been adapted and reused multiple times because of various causes of obsolescence (Remøy, 2014). Thus, building adaptation is inevitable and needs to be facilitated in a sustainable and long-lasting way (Beadle *et al.*, 2008; Capolongo *et al.*, 2016; Rockow *et al.*, 2021). This can be fulfilled by promoting circular building adaptability (CBA) in building adaptation projects (Hamida *et al.*, 2023a).

In Chapter 2, CBA has been defined as "*the capacity to contextually and physically alter the built environment and sustain its usefulness, whilst keeping the building asset in a closed-reversible value chain*" (Hamida *et al.*, 2023b). For instance, using demountable building products can simultaneously promote building adaptability and circularity (Geldermans, 2016). By bringing together CBA and adaptive reuse, long-lasting utility of the built environment can be promoted while minimizing waste generation (Hamida *et al.*, 2023a), as the CE model could prioritize economic and environmental considerations over the societal ones due to the availability of different definitions and models of CE (Kirchherr *et al.*, 2017). Relevant studies have conceptualized how circularity can be aligned with adaptive reuse (Foster, 2020; Girard and Vecco, 2021; Hamida *et al.*, 2023b; van Laar *et al.*, 2024) or explored the current application of circularity- and adaptability-related strategies in adaptive reuse projects (Hamida *et al.*, 2023a, b; Kaya *et al.*, 2021; Rockow *et al.*, 2021). It is worth noting that CE in adaptive reuse is still emerging, in which lack of knowledge about it in the industry and shortcomings in existing frameworks are among the inhibiting factors to its implementation in Europe (Pintossi *et al.*, 2023). For instance, an exploratory study by Kaya *et al.* (2021) pointed out that few building stakeholders in the Netherlands recognize the alignment of adaptive reuse with CE. In this regard, different decision-making and evaluation-oriented tools have been developed for the circular adaptive reuse of heritage buildings (Gravagnuolo *et al.*, 2017, 2024; Kaya *et al.*, 2021). However, there is currently no guiding and design-oriented framework that can practically provide designers and developers with knowledge on the applicable circularity- and adaptability-oriented strategies in adaptive reuse projects (Hamida *et al.*, 2023c).

Accordingly, this chapter aims to develop and collaboratively validate a guiding framework for CBA in adaptive reuse (CBA-AR) projects in general within the context of the Netherlands. A participatory research approach was followed in this chapter (see subsection 4.4). By virtue of various national initiatives and policies aiming at facilitating the transition to CE in the Netherlands, it is worth mentioning that the Dutch building industry has become a pioneering sector in terms of adopting circularity in practice (Cramer, 2020; Tserng *et al.*, 2021). This chapter bridges a gap between theory and practice by providing designers, property developers, and policymakers with applicable strategies for CBA in adaptive reuse along with the factors that either facilitate or impede the implementation of those strategies. In the building and real estate sectors, designers and property developers can use the CBA-AR framework as a checklist and a reporting tool for promoting circularity in the reuse of existing buildings. Researchers can use the components of this framework in the further development of decision-making tools. Policymakers can amend existing adaptive reuse regulations considering the components of the proposed CBA-AR framework in this study. Thereby, this study ultimately contributes to paving the way for a resource-efficient and future-proof redevelopment of the built-environment.

4.4 Co-development methodology: A participatory research-oriented approach

4.4.1 Overview and theoretical background of the co-development approach

The present study in this chapter adopted a participatory research-oriented approach, using co-creation workshops as a primary data collection method. The workshops were preceded by archival research and triangulated with structured interviews. Figure 4.2 illustrates the flowchart of this participatory study. Participatory research is a convergence approach that actively brings research and practice together by involving participants that are acquainted with a process or phenomenon of interest in the research conduct (Bergold and Stefan, 2012). This approach can facilitate a collaborative creation of knowledge – known as co-creation of knowledge (Rock *et al.*, 2018). The concept of co-creation has emerged and is used across different fields with different meanings. Overall, this concept tends to focus on how individuals can collaborate with each other, usually in a form of a consortium, to create meanings or meet certain needs whereas the organizer of the collaboration facilitates this collaboration and leverages its outcomes without total dominance (Ind and Coates, 2013). Research workshops are among the applicable participatory research methods for co-creating knowledge or objects (Thoring *et al.*, 2020). Research workshops can also be also employed for developing, applying and testing solutions (Fisher, 2004).

Workshops represent a useful method to test and validate practice-oriented frameworks for new or emerging practices in the built environment. For instance, van Stijn and Gruis (2020) used a series of student workshops as a means to test a theory-based design tool for circular building components. In addition, Aigwi *et al.* (2022) organized a workshop with various stakeholders involved adaptive reuse of historical buildings in in Auckland, New Zealand, to test and validate the applicability of a decision-making framework for the adaptive reuse of underutilized heritage buildings.

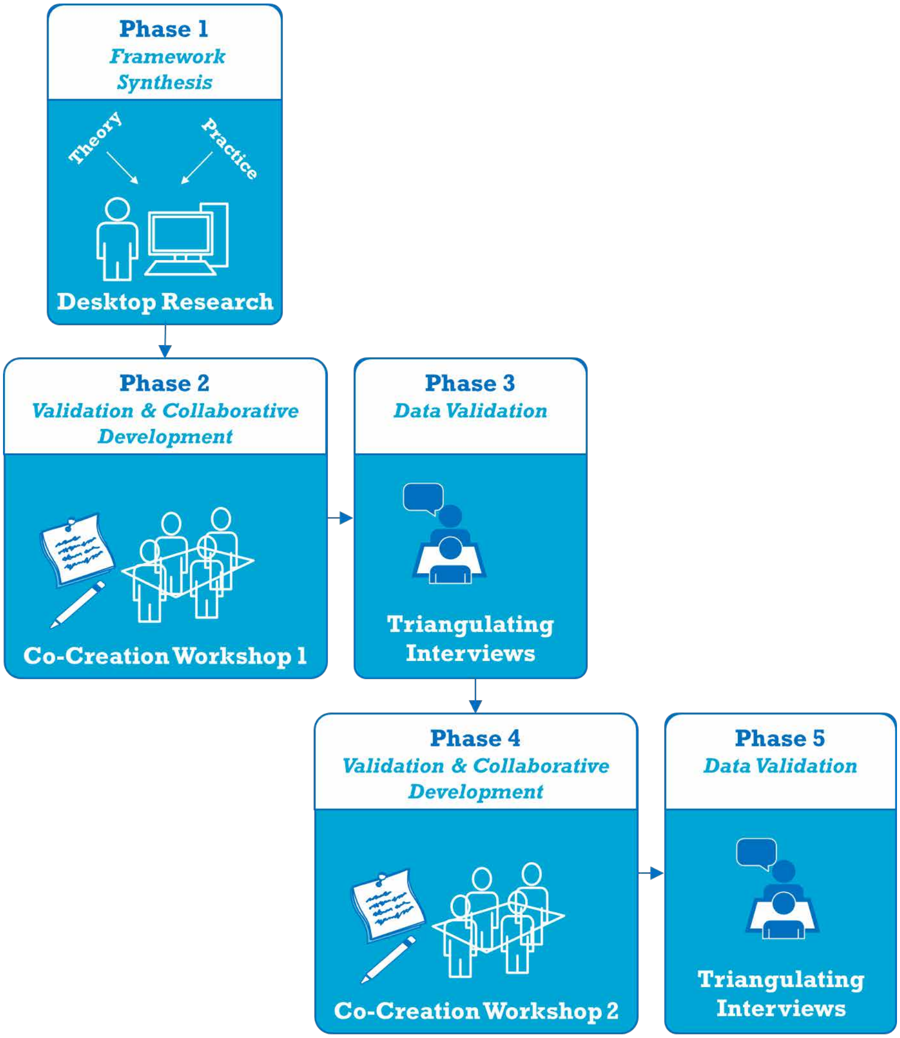


FIG. 4.2 Flowchart of the participatory study

In this study, two co-creation workshops were facilitated with building and real estate practitioners in the Netherlands to collaboratively validate and expand a theory- and practice-based framework for CBA-AR (see subsection 4.5). The framework acted as a theme of discussion for the collaborative and creative interactions among the participants. The methodological framework by Storvang *et al.* (2018) for diagnosing, planning, facilitating and analyzing research workshops was followed in this study, considering the three main roles of respectively the researcher, facilitator and participants (Table 4.1).

TABLE 4.1 The role of researcher, facilitator, and participants in the diagnosing, planning, facilitating, and analyzing two co-creation workshops

Phase	Role	Task/consideration
Diagnosing phase	Researcher*	Developing the CBA-AR framework based on knowledge gained from theory and practice
	Facilitator	Defining and contacting based on his/her research field
	Participants	The participants, who are practitioners who have been involved in implementing circularity and adaptability related strategies in adaptive reuse, was preliminary defined by the researcher
Planning phase	Researcher*	Designing the protocol of the workshop: *content* (invitation, framework, presentation and questions), *boundary object* (material and tools: sheets and standard colours of sticky notes) and *activities* (required tasks from participants) of each workshop.
	Facilitator*	Reviewing and revising the workshop protocol
	Participants	The considered participants were contacted to set up a date of the workshop
Facilitating phase	Researcher*	Moderating the workshop, by presenting the program of the workshop, introducing the framework and managing the activities with the facilitator
	Facilitator*	Co-moderating the workshop by observing and documenting the outcomes and interactions among the participants
	Participants*	Validating and collaboratively expanding the components of the framework • *Workshop 1*: Validating and collaboratively expanding the CBA strategies • *Workshop 2*: Validating and collaboratively expanding the enabling and inhibiting factors as well as evaluating the CBA strategies in terms of their effectiveness, economic feasibility, and applicability
Analyzing phase	Researcher*	Reporting, analyzing, validating, and interpreting the findings deductively. A technical report of the findings was compiled.
	Facilitator*	
	Participants*	Reflecting on the outcomes of the workshop.

**Active role in the phase*

4.4.2 Data collection

Archival research

Archival research was conducted to develop the first version of the CBA-AR framework based on the knowledge gained from literature review and case studies (Hamida *et al.*, 2023a, b). Archival research comprises a wide range of activities facilitating the review and exploration of past documents created by organizations or individuals (Ventresca and Mohr, 2002). In this study, knowledge about the CBA strategies and their enabling and inhibiting factors were extracted and brought together as key components of the framework. The first version of the framework, which is a theory- and practice-based synthesis, comprised 30 CBA strategies as well as 7 enabling and 6 inhibiting factors (see subsection 4.5).

Co-creation workshops

Two co-creation workshops were facilitated on 19-April 2023 and 18-October, respectively. To facilitate a co-creation session without the dominance of a certain practitioner (Ind and Coates, 2013), the two workshops were hosted and organized at the Faculty of Architecture and the Built Environment, TU Delft, Delft, the Netherlands. The workshops were used as a participatory research method to collaboratively validate and expand the components of the developed theory- and practice-based CBA-AR framework. Table 1 presents the roles of the researcher, facilitator, and participants during the diagnosing, planning, facilitating, and analyzing phases.

The first workshop focused on validating and collaboratively expanding the CBA strategies. The second workshop had a threefold focus: 1) validating the defined influence of the previously defined enabling and inhibiting factors on the CBA strategies; 2) collaboratively expanding the defined enabling and inhibiting factors and 3) evaluating the CBA strategies in terms of their effectiveness in promoting CBA, economic feasibility and applicability in practice using a 5-point rating system (Table 4.2). Collective weighting is a useful technique to arrive at a consensus on the priority and importance of certain measures within a series of possible measures for a certain building practice, particularly when such a practice is a multidisciplinary process and involves different experts with various perspectives. For instance, Capolongo *et al.* (2016) utilized this technique in a focus group discussion to prioritize the importance of design parameters for incorporating flexibility in healthcare buildings.

TABLE 4.2 The adopted 5-point rating scheme in workshop 2

Scale	Evaluation criterion		
	Effectiveness in promoting CBA	Applicability in practice	Economic feasibility
4 – 5	Extremely effective	Extremely applicable	Entirely feasible
3 – 3.9	Very effective	Very applicable	Quite feasible
2 – 2.9	Effective	Applicable	Feasible
1 – 1.9	Somewhat effective	Somewhat applicable	Barely feasible
0 – 0.9	Not effective	Not applicable	Not feasible

In both workshops, experts on circularity, adaptability, and adaptive reuse were invited from the Dutch building and real estate sectors. The invitees’ experience in these three domains was a key criterion for their selection as participants. The invited participants were experts from different professions in the building industry and real estate market, due to the diversity and variety of involved stakeholders and professionals in adaptive reuse projects and circularity built environment

(CBE). Subsection 4.6 provides further information about the profile of the involved participants. In both workshops, the framework was explained before the creative session.

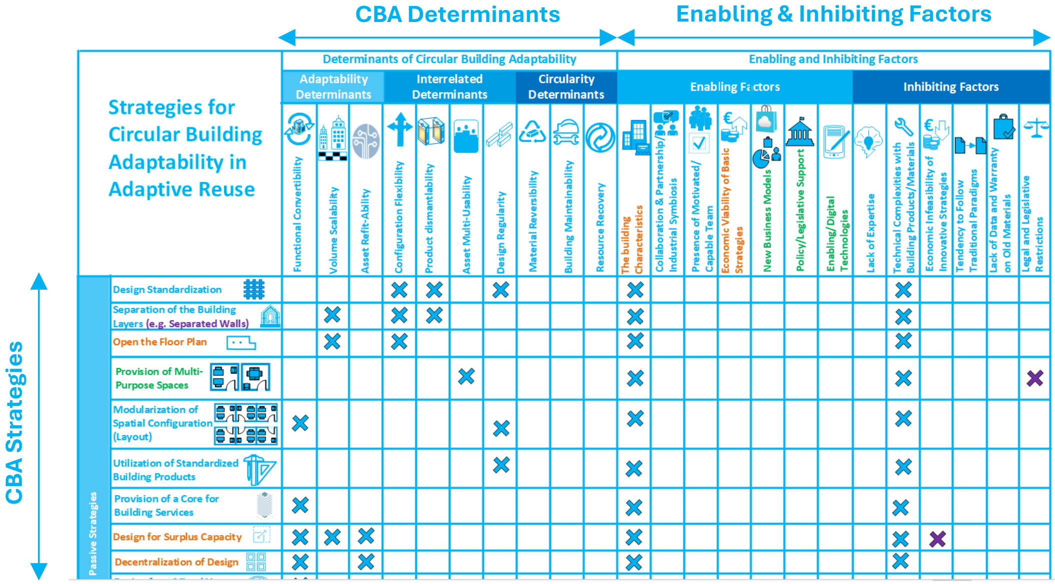
4.4.3 Data analysis and validation

The outcomes of the two workshops were deductively reported and analyzed, using the so-called theory-driven analysis. In qualitative research, this approach entails borrowing an existing conceptual model or theory to guide the coding and analysis of data (Saunders *et al.*, 2007). As the CBA-AR is the essence of this chapter, the components of interests – the CBA strategies and their enabling and inhibiting factors – served as a coding scheme and guide for the analysis of the outcomes of both workshops. The adopted scale in the 5-point evaluation rating system was used in interpreting the results of the assessment of the applicability, effectiveness, and feasibility of the CBA strategies (Table 4.2), thereby prioritizing the strategies in this regard. To arrive at an overall scoring and rating of the strategies, the average of the received three scores for each strategy was calculated as an overall and general indicator of the acceptability of the strategy. This technique is possible to report an indicative and collective score for scores of related domains in which these domains are independent from each other. However, this technique could overlook differences among the domains, but still, it is beneficial as an indicative measure (Pommerich, 2006).

After each workshop, a technical report of the outcomes was compiled and shared with the participants for their reference and reflection. To validate the results of both workshops, three triangulating interviews with expertise on building circularity, adaptability, and adaptive reuse were conducted to triangulate the outcomes of the workshop. Triangulation is a validation technique for qualitative data, which can be applied by leveraging other sources and investigators to accurately verify the findings, thereby giving a reasonable interpretation (Creswell, 2013). Structured interviews with other experts were conducted and recorded online as a triangulation method. The length of these interviews ranged between 1 and 1h 35min. In the validation of the outcomes of the first workshop, two consultants and one senior researchers were interviewed. The interviewees were asked to validate the practicality and clarity of the added strategies by the participants of the co-creation workshop. In the validation of the outcomes of the second workshops, the interviewees were asked to reflect on the indicated influence of the enabling and inhibiting factors on the CBA strategies as well as reflect on the validity and clarity of the newly added factors.

4.5 A theory-and practice-based framework for circular building adaptability in adaptive reuse

The CBA-AR framework is a knowledge-based synthesis that brings together three components, namely CBA determinants (see sub-subsection 4.5.1), CBA-strategies (see sub-subsection 4.5.2), and the factors that enable or impede those strategies (see subsubsection 4.5.3). Figure 4.3 illustrates the typical layout of the CBA-AR framework. Cambridge Dictionary broadly defines framework as “a system of rules, ideas, or beliefs that is used to plan or decide something” (Cambridge University Press & Assessment, 2021). A conceptual framework acts as a concept-based construct that together links and interprets a certain approach, phenomenon, or philosophy based on knowledge gained from discipline-oriented theories and empirical data (Jabareen, 2009).



Strategies for Circular Building Adaptability in Adaptive Reuse	Determinants of Circular Building Adaptability										Enabling and Inhibiting Factors												
	Adaptability Determinants			Interrelated Determinants				Circularity Determinants			Enabling Factors							Inhibiting Factors					
	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	The building Characteristics	Collaboration & Partnership/Industrial Symbiosis	Presence of Motivated/Capable Team	Economic Viability of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions
Design Standardization				✖	✖		✖				✖								✖				
Separation of the Building Layers (e.g. Separated Walls)		✖		✖	✖						✖								✖				
Open the Floor Plan		✖		✖							✖								✖				
Provision of Multi-Purpose Spaces						✖					✖								✖				✖
Modularization of Spatial Configuration (Layout)	✖						✖				✖								✖				
Utilization of Standardized Building Products							✖				✖								✖				
Provision of a Core for Building Services	✖										✖								✖				
Design for Surplus Capacity	✖	✖	✖								✖								✖	✖			
Decentralization of Design	✖		✖								✖								✖				

FIG. 4.3 The typical layout of the CBA-AR framework

This chapter presents a content-wise conceptual framework that was developed to map the explored CBA strategies in Chapter 3 for circular and adaptable adaptive reuse against their enablers and inhibitors (Hamida *et al.*, 2023a). In this framework, the strategies are mapped to the defined ten determinants in Chapter 2, as these determinants were defined based on an integrative literature review of relevant studies to circularity and adaptability in buildings (Hamida *et al.*, 2023b), including Akhimien *et al.* (2021), Arge (2005), Brand (1994) and Eberhardt *et al.* (2022). Keeping in mind the basic rationale of this chapter and research – adaptive reuse projects need to be circular and adaptable, these determinants systematically and coherently provide a guiding scheme for this study as they bring the principles of building adaptability and circularity together (see sub-subsection 4.5.1). For instance, Ollár (2024) adopted these determinants in identifying strategies for designing circular and adaptable multi-residential buildings in Sweden. Regarding the enabling and inhibiting factors, the exploratory study present in Chapter 3 followed a theory- and practice-oriented approach to specifically explore and reveal the enabling and inhibiting factors to the CBA strategies in demonstration adaptive reuse projects in the Netherlands (Hamida *et al.*, 2023a).

The CBA-AR framework would help practitioners in the building industry and real estate market to convert vacant and obsolete properties in a circular and adaptable manner by bringing together the practical solutions that can promote the CBA qualities with the factors that could facilitate and hinder these solutions. In addition, policy makers can amend existing legislation on the basis of the components of the CBA-AR framework. For instance, Shooshtarian *et al.* (2024) explored and mapped challenges and motivations of applying recycled construction products along with their possible strategies in Australian projects in order to inform policy makers and building practitioner about such kind emerging practices; thereby facilitating the application of CE in practice. Following is a brief description of the three components of the framework.

4.5.1 The 10 determinants of CBA

Although these determinants were defined in Chapter 2 and briefly described in Chapter 3, it is useful to revisit them in this sub-subsection within the context of the CBA-AR framework. In the CBA-AR framework, the determinants are the key pillars as they represent qualities that need to be manifest to promote circularity and adaptability in adaptive reuse. In Chapter 2, ten determinants of CBA were defined, namely "configuration flexibility", "product dismantlability", "asset multi-usability", "design regularity", "functional convertibility", "material reversibility", "building maintainability", "resource recovery", "volume scalability" and "asset refit-ability" (Hamida *et al.*, 2023b). Table 4.3 provides a brief description of each of these determinants (Hamida *et al.*, 2023a).

TABLE 4.3 A brief description of the CBA determinants

Determinant	Brief description
Configuration flexibility	The capacity to reconfigure the layout of spaces without utilizing 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 maximizing the efficiency of their utilization
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 y 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, utilize 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 organization, 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: Chapter 3 (Hamida et al., 2023a)

4.5.2 The CBA strategies

The CBA strategies represent solutions or actions that promote the determinants of CBA. The CBA strategies are grouped under three categories, namely passive, active and operational strategies. Passive strategies comprise solutions that can promote CBA through the building design, while active strategies encompass solutions that foster CBA through the building configuration and user intervention. Operational strategies are process-oriented solutions that promote CBA. The first version of the CBA-AR framework was developed based on findings from previously conducted literature review and case studies (Hamida *et al.*, 2023a, b). This version of the CBA-AR framework comprised 30 strategies, including 14 passive, 5 active, and 11operational strategies (see subsection 4.6).

4.5.3 The enabling and inhibiting factors to the CBA strategies

The enabling and inhibiting factors are influences on the applicability of the CBA strategies. The enabling factors are the influences that facilitate implementing the CBA strategies while the inhibiting factors are the influences that impede them. These factors were incorporated into the CBA-AR framework as aspects to consider by practitioners when implementing CBA strategies, as capturing knowledge about enablers and barriers to a certain building practice could provide practitioners and organizations with a guide to implement or evaluate the effectiveness of such practice (Okere, 2017).

Based on a theory- and practice-oriented approach followed in Chapter 3 (Hamida *et al.* 2023a), seven enabling factors for CBA strategies were defined, namely the building characteristics, collaboration and partnership (industrial symbiosis), presence of a motivated and capable team, the economic viability of basic circular strategies, new business models, legislative support and digital technologies. In addition, six inhibiting factors were also found in the same study, namely lack of expertise, technical complexities with building products and materials, economic infeasibility of innovative/advanced strategies, tendency of organizations and individuals to follow traditional paradigms, lack of data and warranty on old material and legal and legislative restrictions (Hamida *et al.* 2023a) came about. Table 4.4 briefly describes these enabling and inhibiting factors. These 7 enablers and 6 inhibitors were incorporated in the first version of the CBA-AR framework (see subsection 4.6).

TABLE 4.4 A brief description of the enabling and inhibiting factors to the CBA strategies

Enabling factors	
The building characteristics	Availability of flexible size, configuration, and physical and spatial features of the building.
Collaboration and partnership (industrial symbiosis)	The presence of a collaboration and partnership among the actors and stakeholders of the adaptive reuse project.
Presence of a motivated and capable team	The existence of a shared aim among the engineering team for promoting circularity and adaptability in adaptive reuse.
Economic viability of basic circular strategies	Low cost of reusing old building products and affordability of using second hand building products.
New business models	Adoption of new business models for promoting reversibility of assets in the closed- reversible value chain.
Legislative support	Application of supportive policies and regulations that facilitate the development of adaptable buildings and circular solutions.
Digital technologies	Utilization of technologies enabling for using smart building operation, material passports and renewable energy systems .
Inhibiting factors	
Lack of expertise	Lack of knowledgeable and skilled practitioners in CBE.
Technical complexities with building products/material	Poor construction, maladaptive design and building deterioration.
Economic infeasibility of innovative strategies	High cost of restoring deteriorated building elements, reprocessing discarded materials and repurposing old building products.
Tendency of organizations and individuals to follow traditional paradigms	Tendency of organisations and practitioners tend to stick to the linear economy paradigm instead of CE.
Lack of data and warranty on old material	Lack of records on the used building materials and their performance.
Legal and legislative restrictions	Rigidity of existing regulations in terms of applying circular solutions

Source: Adapted from Chapter 3 (Hamida et al., 2023a)

As adaptive reuse projects involve various building practitioners and stakeholders (Foster, 2020; Hamida and Hassanain, 2022; Wilkinson, 2014), the main users of this framework are practitioners from the building industry and real estate market, namely designers, contractors, developers, investors, and facilities managers. Regulators and policy-makers can use this framework in amending or developing legislation for adaptive reuse.

The practical contribution of the CBA-AR framework lies in its usability as an informative and guiding tool such as a checklist by practitioners from the building and real estate sectors. Furthermore, the CBA-AR framework can be utilized by professional organizations as an instrument for reporting the promotion of sustainability in adaptive reuse, as it aligns with the EU Taxonomy Compass for the transition to CE without a significant harm to water, climate mitigation, climate change adaptation, pollution prevention, and biodiversity (EU Taxonomy Navigator, 2020). In particular, the CBA-AR framework can guide practitioners to design for key aspects mentioned in the EU Taxonomy Navigator (2020), namely design for resource efficiency, adaptability, flexibility and disassembly with the aim of enabling for reusability and recyclability of materials.

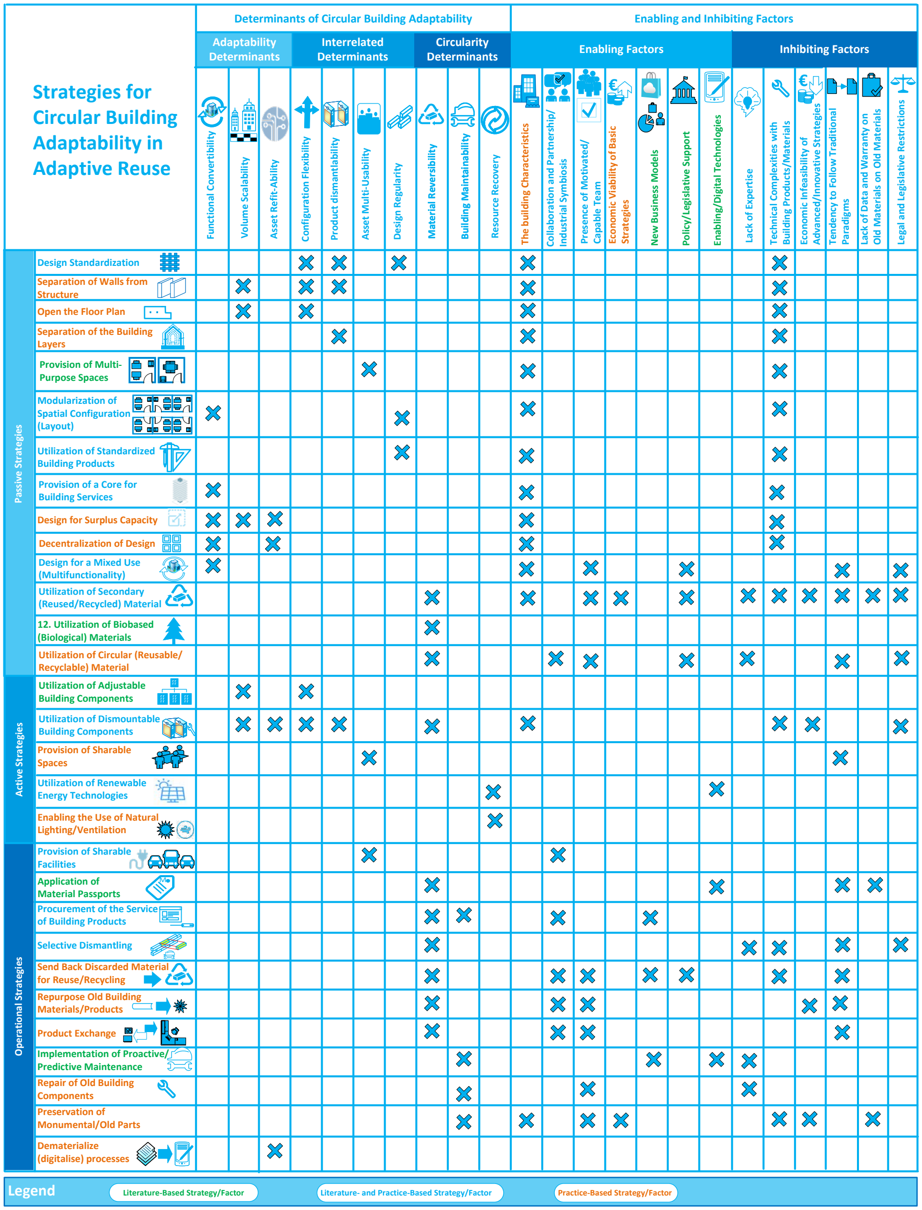
TOC

4.6 Findings

This subsection presents findings of collaboratively developing a guiding framework for CBA in adaptive reuse projects based on a participatory approach that involved building and real estate practitioners who have experience with building circularity, adaptable design, and adaptive reuse projects in the Netherlands. In the first co-creation workshop, six experts participated, including three architects, a project manager, a researcher and a senior property developer. In the second workshop, nine experts joined the workshop, including three architects, two consultants, a project manager, a real estate developer, a researcher, and an R&D manager at a real estate development firm.

4.6.1 Overview

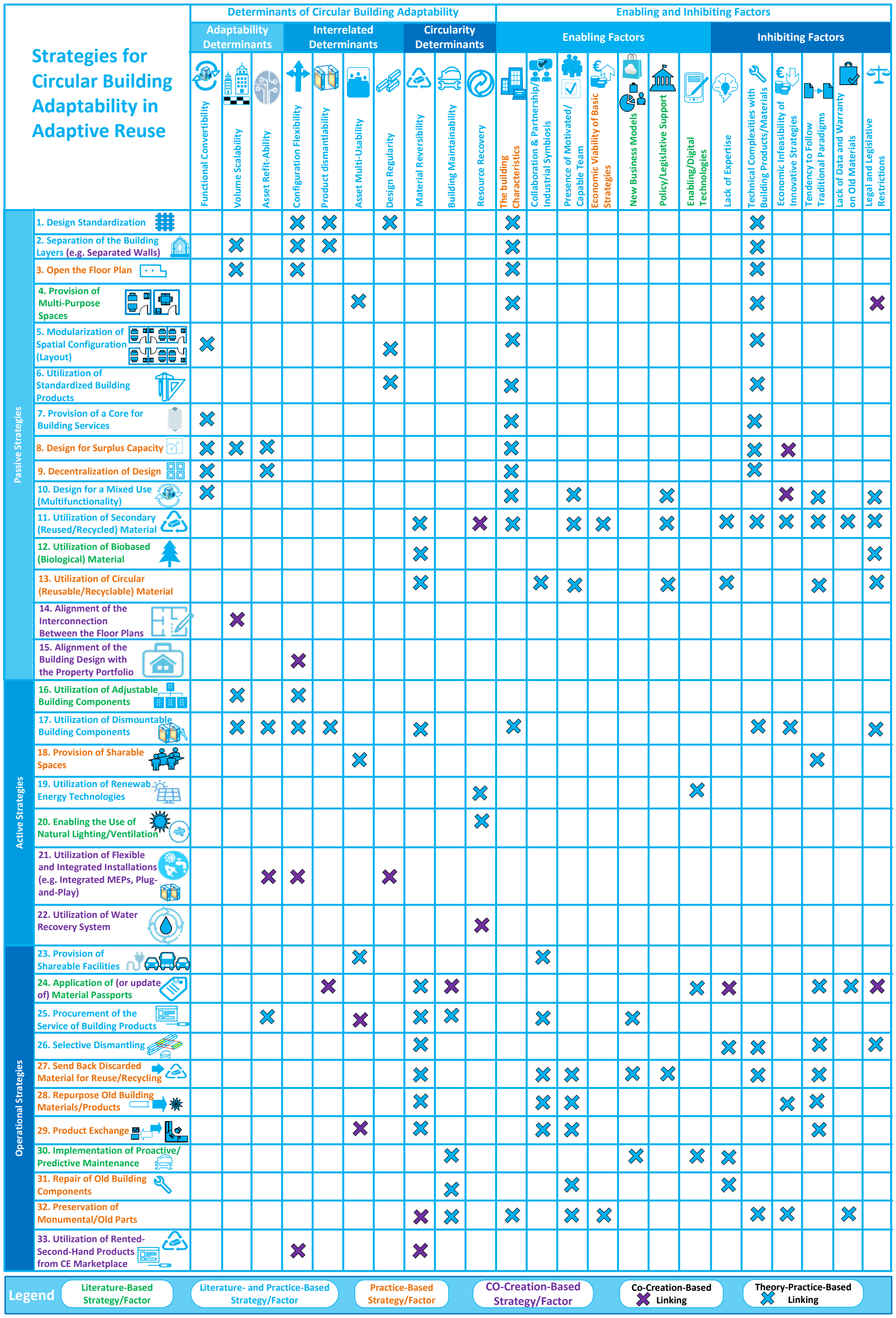
Figure 4.4 presents the first version of the framework which was developed based on archival research. Figure 4.5 presents the revised version of the framework based on the outcomes of the first co-workshop and three structured interviews. Figure 4.6 presents the final version of the framework based on the outcomes of the second workshop and the other 3 structured interviews. In overview, the outcomes of the two workshops and the 6 triangulating interviews contributed to adding new strategies, rephrasing existing strategies, excluding a strategy, combining two strategies, linking the enabling and inhibiting factors to many strategies, and adding other enabling and inhibiting factors. Furthermore, the outcomes of the evaluation of the CBA strategies in terms of their effectiveness, feasibility and applicability led to an criterion-specific prioritization of the strategies based on the received scores, also an overall prioritization of the strategies based on the average of the three scores. Appendix B presents the outcomes of validating and collaboratively expanding the CBA strategies. Appendix C and Appendix D present outcomes of validating and collaboratively expanding the enabling and inhibiting factors,respectively. Appendix E presents the outcomes of collaboratively rating the CBA strategies.



	Strategies for Circular Building Adaptability in Adaptive Reuse	Determinants of Circular Building Adaptability										Enabling and Inhibiting Factors												
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants			Enabling Factors							Inhibiting Factors					
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	The building Characteristics	Collaboration and Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Viability of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Advanced/Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials on Old Materials	Legal and Legislative Restrictions
Passive Strategies	Design Standardization				✖	✖		✖				✖								✖				
	Separation of Walls from Structure		✖		✖	✖						✖								✖				
	Open the Floor Plan		✖		✖							✖								✖				
	Separation of the Building Layers					✖						✖								✖				
	Provision of Multi-Purpose Spaces						✖					✖								✖				
	Modularization of Spatial Configuration (Layout)	✖						✖				✖								✖				
	Utilization of Standardized Building Products							✖				✖								✖				
	Provision of a Core for Building Services	✖										✖								✖				
	Design for Surplus Capacity	✖	✖	✖								✖								✖				
	Decentralization of Design	✖		✖								✖								✖				
	Design for a Mixed Use (Multifunctionality)	✖										✖		✖			✖					✖		✖
	Utilization of Secondary (Reused/Recycled) Material								✖			✖		✖	✖		✖		✖	✖	✖	✖	✖	✖
	12. Utilization of Biobased (Biological) Materials								✖															
	Utilization of Circular (Reusable/ Recyclable) Material								✖				✖	✖			✖		✖			✖		✖
Active Strategies	Utilization of Adjustable Building Components		✖		✖																			
	Utilization of Dismountable Building Components		✖	✖	✖	✖			✖			✖								✖	✖			✖
	Provision of Sharable Spaces						✖															✖		
	Utilization of Renewable Energy Technologies										✖							✖						
	Enabling the Use of Natural Lighting/Ventilation										✖													
Operational Strategies	Provision of Sharable Facilities						✖						✖											
	Application of Material Passports								✖									✖				✖	✖	
	Procurement of the Service of Building Products								✖	✖			✖			✖								
	Selective Dismantling								✖										✖	✖		✖		✖
	Send Back Discarded Material for Reuse/Recycling								✖				✖	✖		✖	✖			✖		✖		
	Repurpose Old Building Materials/Products								✖				✖	✖							✖	✖		
	Product Exchange								✖				✖	✖								✖		
	Implementation of Proactive/ Predictive Maintenance									✖						✖		✖	✖					
	Repair of Old Building Components									✖				✖					✖					
	Preservation of Monumental/Old Parts									✖		✖		✖	✖					✖	✖		✖	
	Dematerialize (digitalise) processes			✖																				

Legend: Literature-Based Strategy/Factor; Literature- and Practice-Based Strategy/Factor; Practice-Based Strategy/Factor

FIG. 4.4 Components of the first version of the CBA-AR framework



Strategies for Circular Building Adaptability in Adaptive Reuse		Determinants of Circular Building Adaptability										Enabling and Inhibiting Factors												
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants			Enabling Factors							Inhibiting Factors					
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Viability of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions
Passive Strategies	1. Design Standardization				X	X		X				X								X				
	2. Separation of the Building Layers (e.g. Separated Walls)		X		X	X						X								X				
	3. Open the Floor Plan		X		X							X								X				
	4. Provision of Multi-Purpose Spaces						X					X								X				X
	5. Modularization of Spatial Configuration (Layout)	X						X				X								X				
	6. Utilization of Standardized Building Products							X				X								X				
	7. Provision of a Core for Building Services	X										X								X				
	8. Design for Surplus Capacity	X	X	X								X								X	X			
	9. Decentralization of Design	X		X								X								X				
	10. Design for a Mixed Use (Multifunctionality)	X										X		X			X				X	X		X
	11. Utilization of Secondary (Reused/Recycled) Material								X		X	X		X	X		X		X	X	X	X	X	X
	12. Utilization of Biobased (Biological) Material								X															X
	13. Utilization of Circular (Reusable/Recyclable) Material								X				X	X			X		X			X		X
	14. Alignment of the Interconnection Between the Floor Plans		X																					
	15. Alignment of the Building Design with the Property Portfolio				X																			
Active Strategies	16. Utilization of Adjustable Building Components		X		X																			
	17. Utilization of Dismountable Building Components		X	X	X	X			X			X								X	X			X
	18. Provision of Sharable Spaces						X															X		
	19. Utilization of Renewab Energy Technologies										X							X						
	20. Enabling the Use of Natural Lighting/Ventilation										X													
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)			X	X			X																
	22. Utilization of Water Recovery System										X													
Operational Strategies	23. Provision of Shareable Facilities						X						X											
	24. Application of (or update of) Material Passports					X			X	X								X	X			X	X	X
	25. Procurement of the Service of Building Products			X			X		X	X			X			X								
	26. Selective Dismantling								X										X	X		X		X
	27. Send Back Discarded Material for Reuse/Recycling								X				X	X		X	X			X		X		
	28. Repurpose Old Building Materials/Products								X				X	X							X	X		
	29. Product Exchange						X		X				X	X								X		
	30. Implementation of Proactive/ Predictive Maintenance									X						X		X	X					
	31. Repair of Old Building Components									X				X					X					
	32. Preservation of Monumental/Old Parts								X	X		X		X	X					X	X		X	
	33. Utilization of Rented-Second-Hand Products from CE Marketplace				X				X															

Legend
Literature-Based Strategy/Factor
Literature- and Practice-Based Strategy/Factor
Practice-Based Strategy/Factor
CO-Creation-Based Strategy/Factor
X Co-Creation-Based Linking
X Theory-Practice-Based Linking

FIG. 4.5 The revised version of the CBA-AR framework based on the outcomes of the first co-creation workshops and three structured interviews

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	Strategies for Circular Building Adaptability in Adaptive Reuse	Determinants of Circular Building Adaptability									
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Passive Strategies	1. Design Standardization				✕	✕		✕			
	2. Separation of the Building Layers (e.g. Separated Walls)		✕		✕	✕					
	3. Open the Floor Plan		✕		✕						
	4. Provision of Multi-Purpose Spaces						✕				
	5. Modularization of Spatial Configuration (Layout)	✕						✕			
	6. Utilization of Standardized Building Products							✕	✕		
	7. Provision of a Core for Building Services	✕									
	8. Design for Surplus Capacity	✕	✕	✕							
	9. Compartmentalization of Design	✕		✕							
	10. Design for a Mixed Use (Multifunctionality)	✕									
	11. Utilization of Secondary (Reused/Recycled) Materials								✕		✕
	12. Utilization of Biobased (Biological) Materials								✕		✕
	13. Utilization of Circular (Reusable/Recyclable) Materials								✕		
	14. Alignment of the Interconnection Between the Floor Plans		✕								
	15. Alignment of the Building Design with the Real Estate Strategy				✕						

Legend Literature-Based Strategy/Factor | Literature- and Practice-Based Strategy/Factor | Practice-Based Strategy/Factor

FIG. 4.6 The finalized version of the CBA-AR framework based on the outcomes of the second co-creation workshops and three structured interviews

	Enabling and Inhibiting Factors																	Evaluation of the Strategies			
	Enabling Factors										Inhibiting Factors										
	The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
	✕	✖					✖					✕					✖	4	3	5	4
	✕											✕	✖				✖	5	3	4	4
	✕			✖								~~✕~~	✖			✖		4	3	3	3.3
	✕			✖	✖							✕	✖			✖		4.5	3	4.5	4
	✕	✖		✖			✖					~~✕~~	✖			✖		4.5	3	4	3.8
	✕			✖								✕						3	4	4.5	3.8
	✕											✕	✖					3	3	3	3
	✕				✖			✖				✕	✖			✖		4	4	3	3.6
	✕											✕	✖			✖		4	3	2	3
	✕		✕	✖		✕		✖			✖	✖	✖	✕		✕		5	3	2	3.3
	✕		✕	✕		✕			✖	✖	~~✕~~	✕	✕	✕	✕	✕	✖	5	2	1	2.6
	✖		✖		✖				✖	✖	✖		✖			✕		4	3.5	2	3.1
	✖	✕	✕		✖	✕			✖	✖	✕		✖	✕		✕		5	3.5	2	3.5
	✖														✖			3	3	4	3.3
	✖						✖											4	4	5	4.3

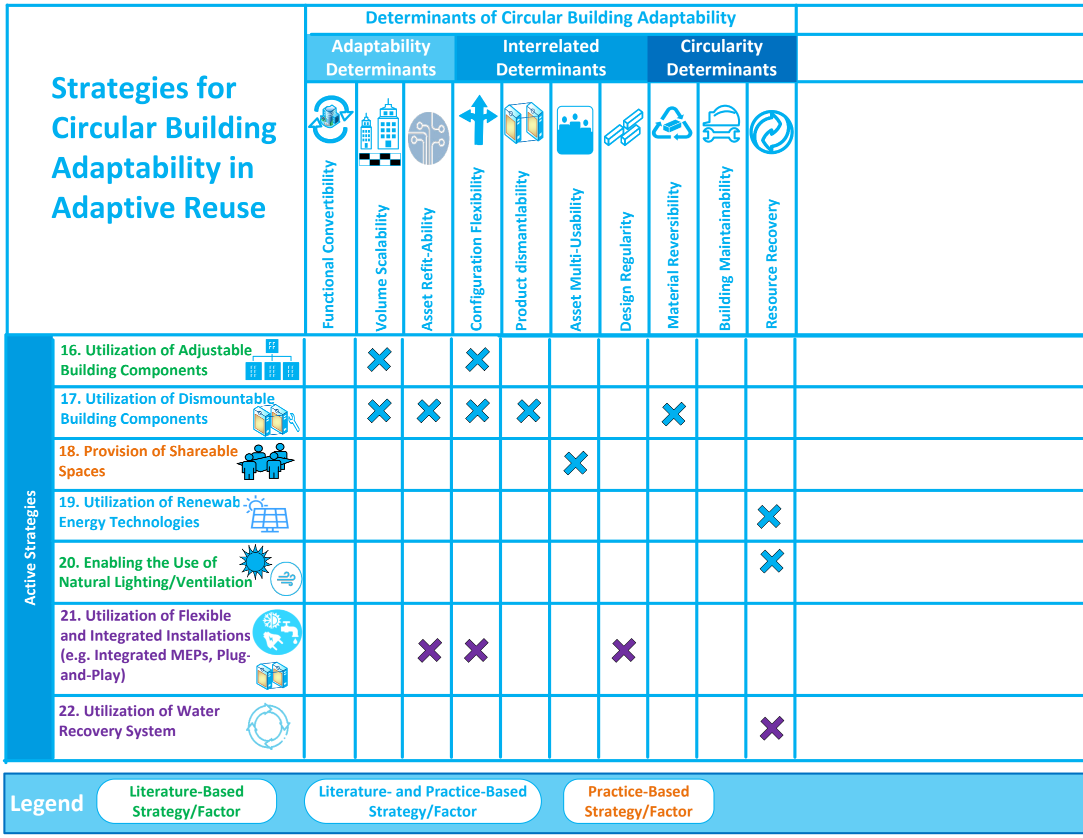
CO-Creation-Based Strategy/Factor

Co-Creation-Based ✖ Linking

Theory-Practice-Based ✕ Linking

Excluded Connection by ~~✕~~ Participants

Revised Text in Workshop 2



Strategies for Circular Building Adaptability in Adaptive Reuse		Determinants of Circular Building Adaptability									
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Active Strategies	16. Utilization of Adjustable Building Components		✕		✕						
	17. Utilization of Dismountable Building Components		✕	✕	✕	✕			✕		
	18. Provision of Shareable Spaces						✕				
	19. Utilization of Renewab Energy Technologies										✕
	20. Enabling the Use of Natural Lighting/Ventilation										✕
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)			✕	✕			✕			
	22. Utilization of Water Recovery System										✕

Legend	Literature-Based Strategy/Factor	Literature- and Practice-Based Strategy/Factor	Practice-Based Strategy/Factor

FIG. 4.6 The finalized version of the CBA-AR framework based on the outcomes of the second co-creation workshops and three structured interviews

	Enabling and Inhibiting Factors																	Evaluation of the Strategies			
	Enabling Factors										Inhibiting Factors										
	The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
	✖											✖	✖				✖	4	4.5	3	3.8
	✕	✖	✖									✕	✕			✕	✖	5	4.5	4.5	4.6
	✖				✖			✖		✖				✕		✖		3	3	5	3.6
	✖		✖				✕	✖	✖	✖			✖					3	5	5	4.3
	✖								✖				✖					4	3	4	3.6
												✖	✖				✖	4	5	5	4.6
									✖			✖	✖				✖	5	3	4	4

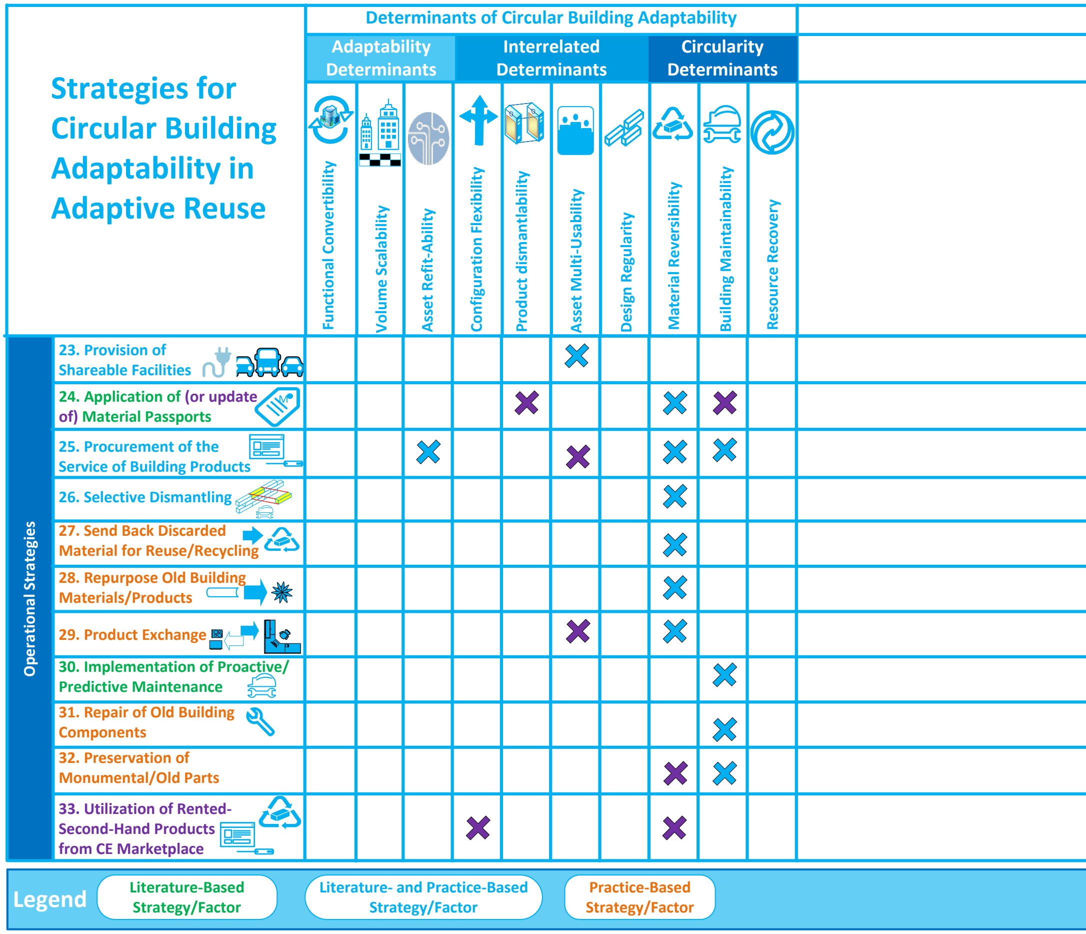
CO-Creation-Based Strategy/Factor

Co-Creation-Based ✖ Linking

Theory-Practice-Based ✕ Linking

Excluded Connection by ~~✖~~ Participants

Revised Text in Workshop 2



Strategies for Circular Building Adaptability in Adaptive Reuse		Determinants of Circular Building Adaptability									
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Operational Strategies	23. Provision of Shareable Facilities						✕				
	24. Application of (or update of) Material Passports					✕			✕	✕	
	25. Procurement of the Service of Building Products			✕			✕		✕	✕	
	26. Selective Dismantling								✕		
	27. Send Back Discarded Material for Reuse/Recycling								✕		
	28. Repurpose Old Building Materials/Products								✕		
	29. Product Exchange						✕		✕		
	30. Implementation of Proactive/ Predictive Maintenance									✕	
	31. Repair of Old Building Components									✕	
	32. Preservation of Monumental/Old Parts								✕	✕	
	33. Utilization of Rented-Second-Hand Products from CE Marketplace				✕				✕		

Legend: Literature-Based Strategy/Factor | Literature- and Practice-Based Strategy/Factor | Practice-Based Strategy/Factor

FIG. 4.6 The finalized version of the CBA-AR framework based on the outcomes of the second co-creation workshops and three structured interviews

Enabling and Inhibiting Factors																	Evaluation of the Strategies			
Enabling Factors										Inhibiting Factors										
The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
	✕			✖	✖	✖	✖	✖	✖			✖					5	5	5	5
✖	✖	✖				✕		✖		✖	✖	✖	✕	✕	✖	✖	5	5	3	4.3
	✕			✕												✖	4	2.5	2	2.8
	✖	✖		✖	✖					✕	✕	✖	✕	✖	✕		5	2	2.5	3.2
	✕	✕		✕	✕			✖	✖	✖	✕	✖	✕	✖	✖		5	4	3	4
	✕	✕		✖	✖			✖	✖		✖	✕	✕	✖	✖	✖	5	4	2	3.6
	✕	✕		✖	✖	✖		✖	✖		✖	✖	✕	✖	✖	✖	5	2	3	3.3
				✕		✕				✕		✖		✖		✖	4	4.5	3	3.8
		✕		✖	✖					✕	✖	✖		✖		✖	4.5	4	4	4.2
✕		✕	✕								✕	✕		✕	✖		4.5	5	2	3.8
	✖	✖		✖		✖								✖	✖	✖	4.5	2	3.5	3.3

CO-Creation-Based Strategy/Factor

✖ Co-Creation-Based Linking

✕ Theory-Practice-Based Linking

Excluded Connection by Participants

Revised Text in Workshop 2

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4.6.2 Validation and expansion of the CBA strategies

The first workshop – focused on validating and collaboratively expanding the CBA strategies – contributed to adding 11 strategies to the framework, including 4 passive, 3 active and 4 operational strategies. One operational strategy was excluded from the framework, namely “dematerialize the processes”, because of its inapplicability in buildings. The workshop outcomes also contributed to linking some of the strategies to other CBA determinants, also to the previously defined enabling and inhibiting factors. For instance, the participants concluded that the design for a mixed-use can be hindered by its high initial cost. Six of the eleven added strategies in the workshop were excluded by the interviewees, because of their impracticality. For instance, the interviewees excluded a strategy called “connecting buildings through tunnels”, due to its limited applicability in buildings. Two strategies were combined by the interviewees, namely “separation of building layers” and “separation of walls from structure”, as the concept of separating partitions from the structure is inherent in the “shearing layer” concept by Brand (1994). The second operational strategy, “application of material passports”, was rephrased as “application of (or update of) material passports”. The participants rephrased the ninth strategy “decentralization of design” to “compartmentalization of design”. Similarly, the fifteenth strategy was rephrased as “alignment of the building design with the real estate strategy” instead of “alignment of the building design with the property portfolio”, as strategy includes the alignment of real estate portfolio, processes, and spaces. Accordingly, 33 strategies were adopted, including 15 passive, 7 active, and 11 operational strategies (Figures 4.5 and 4.6).

4.6.3 Validation and expansion of the enabling factors

The results of the second workshop indicated that all the enabling factors are valid. The interconnections between the enabling factors and the CBA strategies have been expanded (Figure 4.6). Three interconnections were excluded in the second workshop, yet these exclusions were excluded by the interviewees. The formulation of one enabling factor was refined, namely “economic viability of basic strategies”.

Refinement of the enabling factors and their influence on the CBA strategies

Out of 8 previously mapped relationships between the third enabling factor “presence of motivated/capable team” and 8 CBA strategies, the participants excluded two relationships. The participants excluded that there is an influence of the presence of a motivated/capable team on facilitating the design for a mixed-use as well as repair of old building components, although these relationships were observed in case studies by Hamida *et al.* (2023a). Furthermore, the participants excluded that the support from legislation or policies can be an enabler for the design for a mixed-use. All of these exclusions were excluded by the interviewees, in which an interviewee indicated that the capability of the redevelopment team lays the ground for both, designing for a mixed-use and repairing old building components. In addition, two interviewees indicated that designing a building transformation for a mixed-use is impossible without a support from the legislative support in terms of the zoning polices. The fourth enabling “economic viability of basic strategies” factor was rephrased to “economic feasibility of basic strategies”.

Expansion of the enabling factors

Three enabling factors were added to the framework and mapped to many CBA strategies. The newly added enabling factors are “location of the project”, “certification” and “social acceptance” (Figure 4.6). Following are the outcomes of mapping the newly added enabling factors to the CBA strategies:

- **Location of the project:** The participants perceived the location of the project as an enabler for 5 CBA strategies, namely design for surplus capacity, design for a mixed use, provision of shareable spaces, utilization of renewable energy technologies and provision of shareable facilities.

- **Quality and performance certification:** The participants considered sustainability certification and rating systems, such as BREEAM, as an essential enabler for 11 CBA strategies by means of evaluation. The 11 strategies are: utilization of secondary materials, utilization of circular (reusable/recyclable) materials, utilization of biobased materials, utilization of renewable energy technologies, enabling the use of natural lighting/ventilation, utilization of water recovery system, provision of shareable facilities, application of (or update of) material passports, send back discarded materials for reuse/recycling, repurpose old building materials/products and product exchange.

- **Social acceptance:** The participants arrived at a conclusion that social acceptance, as a society-related factor, plays a significant role in the implementation of 9 out of 33 CBA strategies, including utilization of secondary materials, utilization of circular (reusable/recyclable) materials, utilization of biobased materials, provision of shareable spaces, utilization of renewable energy technologies, provision of shareable facilities, send back discarded materials for reuse/recycling, repurpose old building materials/products and product exchange.

According to the expanded relationships between the enabling factors and the CBA strategies, the results show that “building characteristics”, “presence of motivated/capable team” and “new business models” have a direct bearing on facilitating the CBA strategies. These factors were connected to 22, 14, and 14 CBA strategies, respectively (Figure 4.6). However, one of the interviewees who validated the findings indicated that technologies and digitalization are enabling factors for circularity-oriented strategies, while new business models should illustrate the cost-benefit aspects of implementing certain strategies.

4.6.4 Validation and expansion of the inhibiting factors

The outcomes of the second workshop indicate that the previously identified 6 inhibiting factors are valid (Figure 4.6). Out of the 6 inhibiting factors, the interconnections between 5 inhibiting factors and the CBA strategies have been expanded in the second workshop. In the second workshop, 7 interconnections were excluded, yet only 3 exclusions were adopted based on the outcomes of the triangulating interviews.

Refinement of the inhibiting factors and their influence on the CBA strategies

In the second workshop, the potential effect of the lack of expertise on hindering 4 CBA strategies was excluded, namely: utilization of secondary materials, utilization of circular materials, selective dismantling and repair of old building components. The participants also excluded the influence of the second inhibiting factor “technical complexities with building products/materials” on hindering 3 CBA strategies, namely open the floor plan, provision of multi-purpose spaces and modularization of spatial configuration (Figure 4.6). The participants supported these three exclusions with the argument that these three strategies are technically complex, but cannot be greatly hindered by the technical complexities of building

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products/materials. However, the interviewees took 4 of these exclusions away. The interviewees supported that lack of expertise, as an experience-related factor, can hinder the utilization of circular materials, selective dismantling, and repair of old building components. An interviewee argued that dealing with building components in a circular manner requires technical knowledge. Furthermore, two interviewees concluded that physical limitations with the design of an existing building and the complexity of its composition could impede the possibility of providing multipurpose spaces within the building.

Expansion of the inhibiting factors

During the second workshop, two inhibiting factors were added to the framework and not mapped to any CBA strategy. The two added inhibiting factors are "fragmentation of the building industry" and "lack of ambition". The participants were contacted after the workshop to map both factors to the CBA strategies, so two participants mapped both factors to the CBA strategies. However, the interviews excluded the second added inhibitor, "lack of ambition, " due to its generality and interrelationship with the first inhibitor – lack of expertise. The participants considered the fragmentation of the building industry, in terms of stakeholders and processes, as a key inhibitor to many CBA strategies. As an inhibiting factor, "market fragmentation" was linked to 14 CBA strategies (Figure 4.6), namely design standardization, separation of the building layers, utilization of secondary materials, utilization of adjustable building components, utilization of dismountable building components, utilization of flexible and integrated installations, utilization of water recovery system, application of (or update of) material passports, procurement of the service of building products, repurpose old building materials/products, product exchange, implementation of proactive/predictive maintenance, repair old building components and utilization of rented-second-hand products from CE marketplaces.

According to the expanded relationships, "technical complexities with building products and material", "economic infeasibility of innovative/advanced strategies" and "legal and legislative restrictions" are apparently key inhibitors to the CBA strategies. The results indicate that these three factors could hinder 20, 26 and 18 strategies, respectively. The participants indicate that there is a direct relationship between the possibility to apply material passports in adaptive reuse projects and the technical complexities with building products, due to the difficulty of adding information about the technicalities of materials to material passports. Two of the interviews who triangulated the findings have perceived lack of data as another key inhibitor to the strategies that require dealing with reuse of materials and building products.

4.6.5 Evaluation of the CBA strategies

The evaluation of the strategies contributed to getting a better grasp on the effectiveness, economic feasibility and applicability of the strategies.

Regarding the effectiveness of the strategies in promoting CBA, the results of the evaluation indicate that the effectiveness of the 33 CBA strategies is “extremely effective” as shown in Figure 4.6 and in accordance with the adopted interpretation metrics in Table 4.2.

The applicability of the strategies in practice varied, as the results indicated that it ranges between “applicable” and “extremely applicable”. However, the majority of the strategies have been perceived either “very applicable” or “extremely applicable”, as shown in Figure 4.6. The results point out that 5 strategies have been perceived as “applicable”, 14 as “very applicable” and 14 as “extremely applicable”, respectively.

The evaluation of the CBA strategies in terms of their economic feasibility indicates that the majority of them are economically feasible. As shown in Figure 4.6 and according to the adopted interpretation metrics in Table 4.2, only one strategy has been perceived as “barely feasible”, while the other 32 strategies have been considered as “feasible”, “quite feasible” or “entirely feasible”. Out of the 32 economically feasible CBA strategies, 8 strategies have been perceived as “feasible”, 9 as “quite feasible” and 15 as “entirely feasible”, respectively.

Based on the average of the received rating scores, six strategies can be considered as promising strategies for circular and adaptable building transformation. These strategy are: “alignment of the building design with the real estate strategy”, “utilization of dismountable building components”, “utilization of renewable energy technologies”, “utilization of flexible and integrated installations”, “application of material passports” and “provision of shareable facilities”. However, the results indicate that procuring the service of building products as well as utilizing second-hand materials can be seen as the least promising strategies for circular and adaptable building transformation.

4.7 Discussion

Due to the unavailability of knowledge-based guiding tools for promoting CBA in adaptive reuse projects, this study focused on co-developing as well as collaboratively validating and expanding a content-wise framework for CBA-AR. The CBA-AR framework is a descriptive and content-wise synthesis that brings together three components, namely CBA determinants, the CBA strategies, and the enabling and inhibiting factors for those strategies. A participatory research-driven approach was followed in this chapter. All the involved participants and interviewees are practitioners who have prior experience with building circularity, adaptable design, and adaptive reuse projects in the Netherlands.

4.7.1 Discussion of the main findings

Considering the aim of this chapter, the findings indicate that the majority of the CBA strategies are valid. The followed approach contributed to paraphrasing some strategies, excluding a strategy, combining two strategies, expanding the interrelationships between the strategies and the CBA determinants, as well as expanding and refining the enabling and inhibiting factors including relationship with the CBA strategies.

According to the findings, “utilization of dismountable building components” and “procurement of the service of building products” are apparently the most contributing strategies, because they can promote four CBA determinants. This is justifiable, as dismantlability in building components facilitates the their disassembly and reuse in the future (Akhimien *et al.*, 2021; Eberhardt *et al.*, 2022). Similarly, procuring the service of building paves the way for maintaining, replacing and reusing the procured products instead of discarding them (Iyer-Raniga, 2019; Tserng *et al.*, 2021; Webb *et al.*, 1997). The outcomes of evaluating the CBA strategies indicate that “alignment of the building design with the real estate strategy”, “utilization of dismountable building components”, “utilization of renewable energy technologies”, “utilization of flexible and integrated installations”, “application of material passports” and “provision of shareable facilities” are the most promising strategies in the CBA-AR framework. This is in line with the components of the conceptualized framework by Foster (2020) for CE in adaptive reuse.

The results indicate that most of the previously demonstrated relationships between the CBA strategies and their enabling and inhibiting factors are relevant and valid. The findings point out that “the building characteristics”, “presence of motivated and capable team” and “new business models” play a pivotal role in enabling for implementing the CBA strategies, while “technical complexities with building products and material”, “economic infeasibility of innovative/advanced strategies” and “legal and legislative restrictions” can greatly hinder them. These findings corroborate with observations indicated by Kanters (2020) and Dewagoda *et al.* (2022) which point out that the infrastructure of buildings along with the adoption of new business models facilitate CE in buildings.

Regarding the three most significant inhibitors, the results of this study agree with the findings of Ababio and Lu (2023), AlJaber *et al.* (2023) and Giorgi *et al.* (2020) which indicate that economic, political and technical challenges are main barriers to the application of CE in buildings. The raised technical issues by the participants in regards to the low performance and quality of materials are in line with the empirical observations by Shooshtarian *et al.* (2024).

4.7.2 Reflection on the implications of the participatory study

It is worth noting that that there has been a possibility to refine and expand the three components of the CBA-AR framework along with acquiring further insights into practical aspects. These outcomes were delivered by the virtue of following such a participatory and iterative approach by using a series of two co-creation workshops as a primary research method.

The generalizability of using the CBA-AR framework as a guiding tool by practitioners is possible for different reasons. First, the incorporated strategies into the framework were expanded and validated by practitioners who have practiced with circularity and adaptive reuse in the Dutch building industry and real estate market which are seen as forerunners in operationalizing CE in practice (Cramer, 2020; Tserng *et al.*, 2021). Second, the content of the framework is not only a theory- and concept-based synthesis, as the case of the conceptualized framework by Foster (2020), but rather a synthesis that is based on an integrative outcome of coherently brining findings of theoretical, empirical and participatory research together. Third, the framework does not only link a series of strategies to certain qualities of CBA in adaptive reuse, but rather it coherently connects three components together, namely: strategies, determinants, and enabling and inhibiting factors.

These three components can inform practitioners on what needs to be fostered for a circular and adaptable building transformation, how to promote that and what are the aspects that could facilitate or impede relevant CBA strategies. Furthermore, the incorporated rating of the CBA strategies into the CBA-AR framework provides practitioners with an initial prioritization of the applicability, effectiveness, and feasibility of the CBA strategies. The demonstrated relationships between the strategies and the CBA determinants can guide practitioners, policymakers, and researchers in promoting CBA in the Netherlands.

Technically, designers and property developers can use the CBA-AR framework as a checklist, evaluation tool, and instrument to report sustainable and circular practices in adaptive reuse projects. Scholars can use the components of this framework in developing decision-making tools and assess the impact of the CBA strategies, while policymakers can refer to them in amending existing legislation and regulations of adaptive reuse.

4.7.3 Indication of the limitations of this study and possibilities for future research

The CBA-AR framework is still descriptive and has not been tested yet in terms of its usability and effectiveness in practice, which can be a practical limitation of the applicability of this guiding tool in practice. Further, policy experts were not involved in the co-development process along with the building and property experts who participated in the co-development and validation of the framework These limitations can be further studied and addressed by using an action research-oriented approach.

Action research is a useful, iterative, and self-reflective practice-oriented approach that can be followed to reflect a change in the real world as well as test a theoretical hypothesis in real-world settings (Kemmis *et al.*, 2014). In this regard, the CBA-AR framework can be tested and refined in action through a collaborative and iterative process between professionals and scholars during the design of an adaptive reuse project for circularity and adaptability. The outcomes of such a collaborative and iterative process can further contribute to enhance the design of the framework to facilitate its use in practice.

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4.8 Conclusion and recommendations

The built environment is confronted with multiple challenges related to resource scarcity, climate change, market volatility, technological advances and high energy use. Adaptive reuse is an indispensable form of building alterations and it is a coping strategy for the aforementioned challenges. In light of the call for promoting circularity in the built environment, adaptive reuse is seen as a promising solution that aligns with the principles of CE. As an inevitable process, adaptive reuse should also foster the adaptability to accommodate future changes. However, there has not been a developed framework describing how circularity and adaptability can be brought together in adaptive reuse projects.

This presented study in this chapter focused on collaboratively developing a guiding framework that describes how circularity and adaptability can be brought together and fostered in adaptive reuse projects in general, considering contextual factors that can facilitate or impede the implementation of these strategies. In this regard, the CBA-AR framework is a knowledge-based synthesis that connects a series of strategies to the CBA determinants together, as well as the enabling and inhibiting factors to those strategies.

A participatory research-oriented approach was followed in this chapter. An archival research was carried out first to develop the first version of the framework based on the knowledge gained from the literature review and case studies. Two co-creation workshops were organized with experts from the Dutch building industry and real estate market to collaboratively validate the components of the framework. The outcomes of each workshop were validated through structured interviews.

The followed participatory approach in this chapter contributed to collaboratively refining, combining and expanding the components of the CBA-AR framework – the CBA strategies and their enabling and inhibiting factors – as well as their interrelationships. The refined and expanded version of the CBA-AR framework consist of 33 strategies – including 15 passive, 7 active and 11 operational strategies – along with 10 enabling and 7 inhibiting factors. Overall, the findings indicate that “alignment of the building design with the real estate strategy”, “utilization of dismountable building components”, “utilization of renewable energy technologies”, “utilization of flexible and integrated installations”, “application of material passports” and “provision of shareable facilities” are the most promising CBA strategies. Furthermore, “the building characteristics”, “presence of motivated and capable team” and “new business models” are the key enablers, while “technical complexities with building products and material", "economic infeasibility of innovative/advanced strategies" and "legal and legislative restrictions" are the key inhibitors to the CBA strategies.

These observations can guide practitioners, policymakers, and scholars in promoting CBA in adaptive reuse. Designers and property developers can use the CBA-AR framework as a checklist and a tool for reporting circular activities in the reuse of existing buildings. Researchers can use the components of this framework further in the development of decision-making tools. Policymakers can adapt the components of the CBA-AR framework in amending existing regulations.

Based on these findings, the following recommendations are put forward:

- Designers and property developers of adaptive reuse projects must facilitate future changes efficiently while reducing waste by utilizing dismountable building products and installing flexible and integrated building installations.

- Property developers of adaptive reuse projects need to maintain updated building information as well as apply and update material passports as a record of the utilized building assets and their performance, thereby facilitating the reuse of the building assets afterward.

- New business models should adopted for circularity-oriented strategies, in which the cost-benefit aspects should be illustrated.

- Researchers need to explore ways of sharing knowledge about the CBA strategies and their adoption in practice.

- Future research can focus on testing and reflecting on the effectiveness and usability of the CBA-AR framework in action by following a collaborative and iterative approach that brings professionals and scholars together during the design of adaptive reuse for circularity and adaptability.

Ultimately, the presented CBA-AR framework complements other frameworks available in the relevant literature, by the virtue of its descriptive content which coherently brings three components together on the basis of acquiring and expanding knowledge from the relevant theory and practice as well as an iterative co-creation process. The CBA-AR framework is a descriptive synthesis that has not been tested yet in the real world, which can limit its useability in practice. Moreover, the CBA-AR framework was co-developed with experts from the building industry and real estate market, in which policy experts were not involved in this process.

However, it is worth noting that the content of the CBA-AR framework can set the stage for fostering CBA in future adaptive reuse projects in the Netherlands by the means of knowledge sharing, amendments of current regulations, development of decision-making instruments, and actionable studies. Further research can focus on testing the applicability and effectiveness of using the CBA-AR framework in real practice, by the means of action research which brings knowledge from theory and practice together in the real world.

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5 Making circular strategies work: Advancing an adaptable building framework through action design research

5.1 Overview of chapter 5

Chapter 4 presented a co-developed framework for CBA-AR based on a participatory study bridging the gap between the theoretical and empirical observations in Chapter 2 and Chapter 3, respectively. This chapter answers the fourth research sub-question: How can the developed framework for circular and adaptable adaptive reuse projects be usable and effective in practice? It presents results of testing and reflecting on the applicability and effectiveness of the co-developed CBA-AR framework in the real world, by following a mixed approach of action- and design research. Figure 5.1 illustrates the interconnection between this chapter and the conceptual scheme of this study.

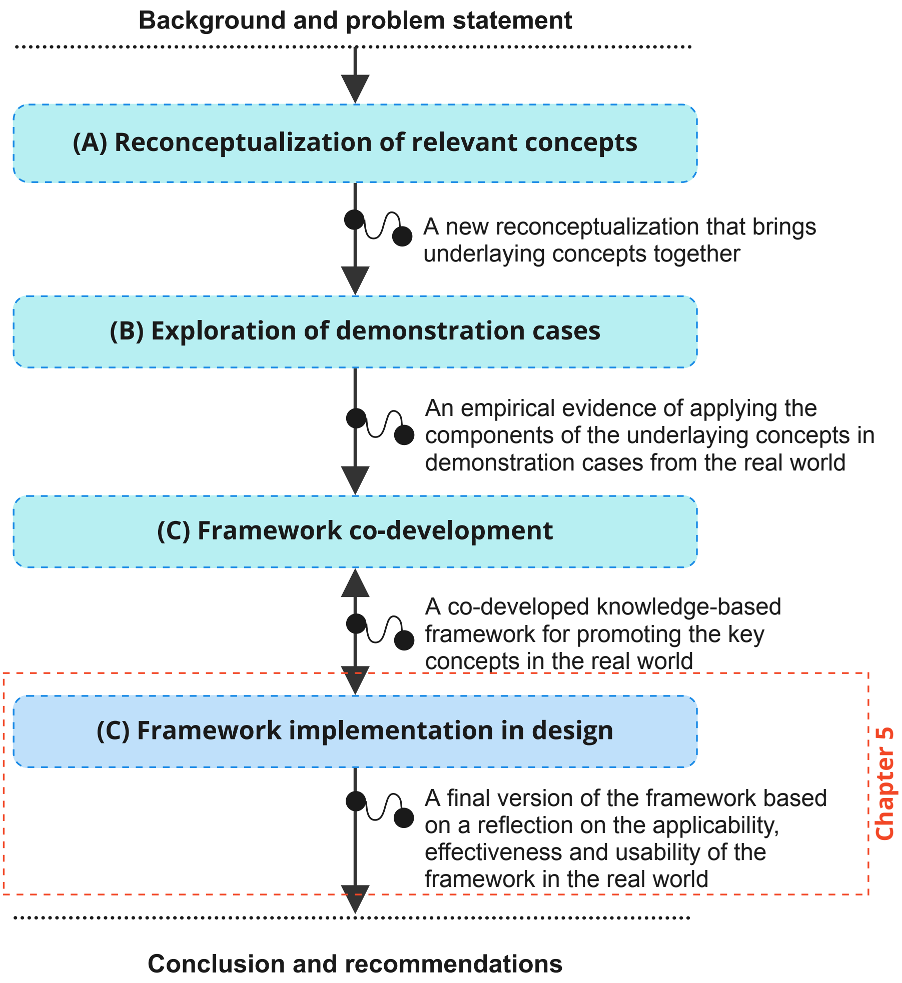

FIG. 5.1 The interconnection between Chapter 5 and the conceptual scheme of this study

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In this chapter, all headings, figures, and tables are renumbered on the basis of the chapter number. The title of the methodology section is renamed to be in line with the content of the chapter. The phrase “the researcher” is used instead of “the first author”. The passive voice is used in this chapter instead of the active voice.

5.2 Abstract

Circular and adaptable strategies in building reuse are key to achieving a resource-efficient and future-proof built environment. Despite significant advances in circular building research, this field is affected by a significant theory-practice gap. To bridge this gap, the presented study in this chapter applied an action design research methodology, implementing a circular building design framework over a five-month period in the context of a Dutch monumental office building reuse. The objective of these interventions was to observe practitioners engaging with the framework and identify the barriers they encountered when considering and applying circular building strategies. The researchers observed that the framework primarily functioned as a descriptive tool. Enhancing its usability and effectiveness required several refinements, including simplifying its self-description, clarifying its strategies through practical solutions and connections to related models, providing robust assessment tools, and improving its accessibility. Through iterative action research conducted during the observation and intervention period, the researchers addressed these issues and advanced the framework. Our design-oriented approach led to the development of key design artifacts: a prescriptive guiding, assessment, and reporting tool; a stepwise approach to streamline application; and a hands-on worksheet for practitioners. These artifacts were integrated into a user-friendly platform, transforming the framework into a practical tool for real-world implementation. For theory, this study incorporates a circular perspective into a usable framework and demonstrates how an action design research approach can co-develop and improve frameworks and their usability and relevance. For practice, the produced artifacts represent boundary objects tailored to practitioners' needs; thereby paving the way for future circular adaptive reuse.

5.3 Introduction

Research on the building sector widely acknowledges the adaptive reuse of buildings as a promising strategy to achieve a circular built environment, owing to its capacity to reuse and prolong building assets and reduce waste(Foster 2020; Gravagnuolo *et al.*, 2017; Kaya *et al.*, 2021). Iselin and Lemer (1993) defined adaptive reuse as "*Conversion of a facility or part of a facility to a use significantly different from that for which it was originally designed*". It refers to the process of repurposing existing residential and non-residential buildings for new usesto serve new requirements (Douglas, 2006). It is implemented as a means to cope with different consequences of market dynamics, such as transforming vacant offices into residential apartments (Remøy, 2010). It is a sustainable approach to urban development and conservation that extends the lifecycle of buildings, reduces waste (Remøy, 2014), and minimizes the environmental impact of demolition and new construction (Foster, 2020).

Despite the booming of research in adaptive reuse over the past two decades, the field still suffers from a significant theory-practice divide (Greco, *et al.*, 2024). A key reason identified in research for this divide is the way the design processes are organized. For instance, Kaya *et al.* (2021) pointed out that building stakeholders in the Netherlands barely recognize the interconnection between adaptive reuse and circularity. This divide stems from the fragmented and often linear nature of traditional design processes, which should become material-centric, as opposed to material decisions as one of the last and list design steps. Traditional design approaches also fail to account for the iterative, collaborative, and interdisciplinary approaches required for adaptive reuse (Greco *et al.*, 2024). Effective adaptive reuse demands a design process that integrates diverse stakeholder perspectives, balances competing priorities, and embraces the complexity of transforming existing structures into sustainable, functional, and context-sensitive spaces (van Laar *et al.*, 2024).

To address the call for bridging the theory-practice divide in adaptive reuse and advancing its integration with circularity, this chapter draws on the existing body of research and practice to develop a set of practical resources tailored to practitioners aiming to promote circularity in this type of projects. While research has identified numerous strategies to foster Circular Building Adaptability (CBA) (Hamida *et al.*, 2023a) (see section 3)—such as demountability, surplus capacity, and design standardization (Akhimien *et al.*, 2021; Rockow *et al.*, 2021)—there remains a gap in translating these strategies into actionable tools that can be seamlessly adopted in real-world projects. This gap is further compounded by barriers like technical constraints, legislative restrictions, and the lack of expertise in circular design processes (Hamida *et al.*, 2023b).

To bridge this divide, this chapter leverages insights from the theory of adaptive reuse and circularity to co-create user-friendly, guidance-oriented tools aimed at addressing the challenges practitioners face. By focusing on practical applicability, these resources are designed to foster the adoption of CBA strategies, offer solutions to common obstacles, and enhance the overall adaptability and longevity of reused buildings. The presented study in this chapter aims to empower professionals to implement circular practices more effectively, contributing to the broader goal of a sustainable and circular built environment. This paper addresses the practical gap in circular building adaptability by testing and refining the usability and effectiveness of the CBA-AR framework through an action- and design research-oriented approach (Collatto *et al*., 2018). Usability refers to the ease of use for practitioners, while effectiveness measures the framework's capacity to enhance circular adaptability in design. The outcomes contribute to the literature by providing methodological insights for the future development of decision-making tools, such as those proposed by Hong and Chen (2017), and offer practical guidance tools for practitioners. Additionally, policy-makers can integrate the refined tools into regulatory frameworks to promote circular adaptive reuse. By bridging this gap, the study aims to advance the circular reuse of built assets and foster sustainable design practices.

5.4 Adaptive reuse and its circularity-oriented frameworks

5.4.1 Adaptive reuse

In the introduction, it is indicated that adaptive reuse is the process of converting existing buildings or part of them to serve new requirements (Iselin and Lemer, 1993). It is also known as building conversion, across-use adaptation, and building transformation, which is a common type of building reuse project. It requires implementing major physical alterations for repurposing and adapting the building to a use different from its original purpose (Douglas, 2006; Shahi *et al.*, 2020; Wilkinson, 2014). It is implemented in existing buildings as a coping strategy to reuse vacant properties (Remøy, 2014), as well as preserve and revitalize heritage buildings and locations (Tu, 2020; Wang and Liu, 2021). In practice, it can be triggered by other factors, such demographic changes, building obsolescence, and market volatility (Ross, 2017).

Adaptive reuse is in line with the sustainability triangle principles, as it can contribute to reducing greenhouse emissions and the costs spent in demolishing existing buildings and rebuilding them (Mohamed *et al.*, 2017). Moreover, this type of building project has been seen as a practice aligning with the principle of CE, owing to its great potential to reuse building assets, prolong their functionality, and therefore, reduce waste and the need for new materials (Foster, 2020). Therefore, as a newly emerging practice, several frameworks and models have been conceptualized to capture the alignment between adaptive reuse and CE and ease its decision-making- and design-related practices (Foster 2020; Gravagnuolo *et al.*, 2017; Hamida *et al.*, 2024)

5.4.2 Frameworks for circularity in adaptive reuse

Conceptual frameworks act as a concept-based constructed network that links and interprets a certain approach, phenomenon, or philosophy based on knowledge gained from discipline-oriented theories and empirical data (Jabareen, 2009); thereby, they contribute to advancing and systematizing knowledge about their components (Rocco and Plakhotnik, 2009). Their construction usually entails appropriating terminologies and usable information associated with the relevant concepts and rules to the particular phenomenon of interest in the form of a specialized system. Therefore, their application in practice involves information-oriented uses such as providing generalized resources for giving meaning and adapting action systems (Hills and Gibson, 1992). In the built environment, frameworks can be used as a means to promote new principles and emerging concepts such as For new emerging principles in the built environment, such as circular design and construction, frameworks can promote these new principles by incorporating different principles and processes (Marchesi and Tavares, 2025; Saradara *et al.*, 2024).

For circular adaptive reuse, Gravagnuolo *et al.*, (2017) conceptually positioned adaptive reuse in a CE-oriented framework, namely the ReSOLVE framework, to provide a series of evaluation criteria for circular adaptive reuse. Similarly, Foster (2020) conceptualized a framework mapping a series of strategies for circular adaptive reuse to the R-ladder model as construct-capturing solutions for promoting circularity in adaptive reuse. Both frameworks are theoretical and based on material-oriented models of CE.

In this chapter, the developed content-wise framework for CBA-AR (see Chapter 4) has been used as a framework and boundary object (Hamida *et al.*, 2024). The framework is based on CBA, which was defined by Hamida *et al.* (2023a) 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." (see Chapter 2). Table 5.1 lists a brief description of these determinants. As a content-wise framework, the CBA-AR is a descriptive synthesis that maps a series of CBA-oriented strategies for adaptive reuse to the defined ten determinants of CBA by Hamida *et al.* (2023a), namely: "configuration flexibility", "product dismantlability", "asset multi-usability", "design regularity", "functional convertibility", "material reversibility", "building maintainability", "resource recovery", "volume scalability", and "asset refit-ability". Table 1 briefly describes these determinants (Hamida *et al.*, 2023b).

TABLE 5.1 A brief description of the CBA determinants

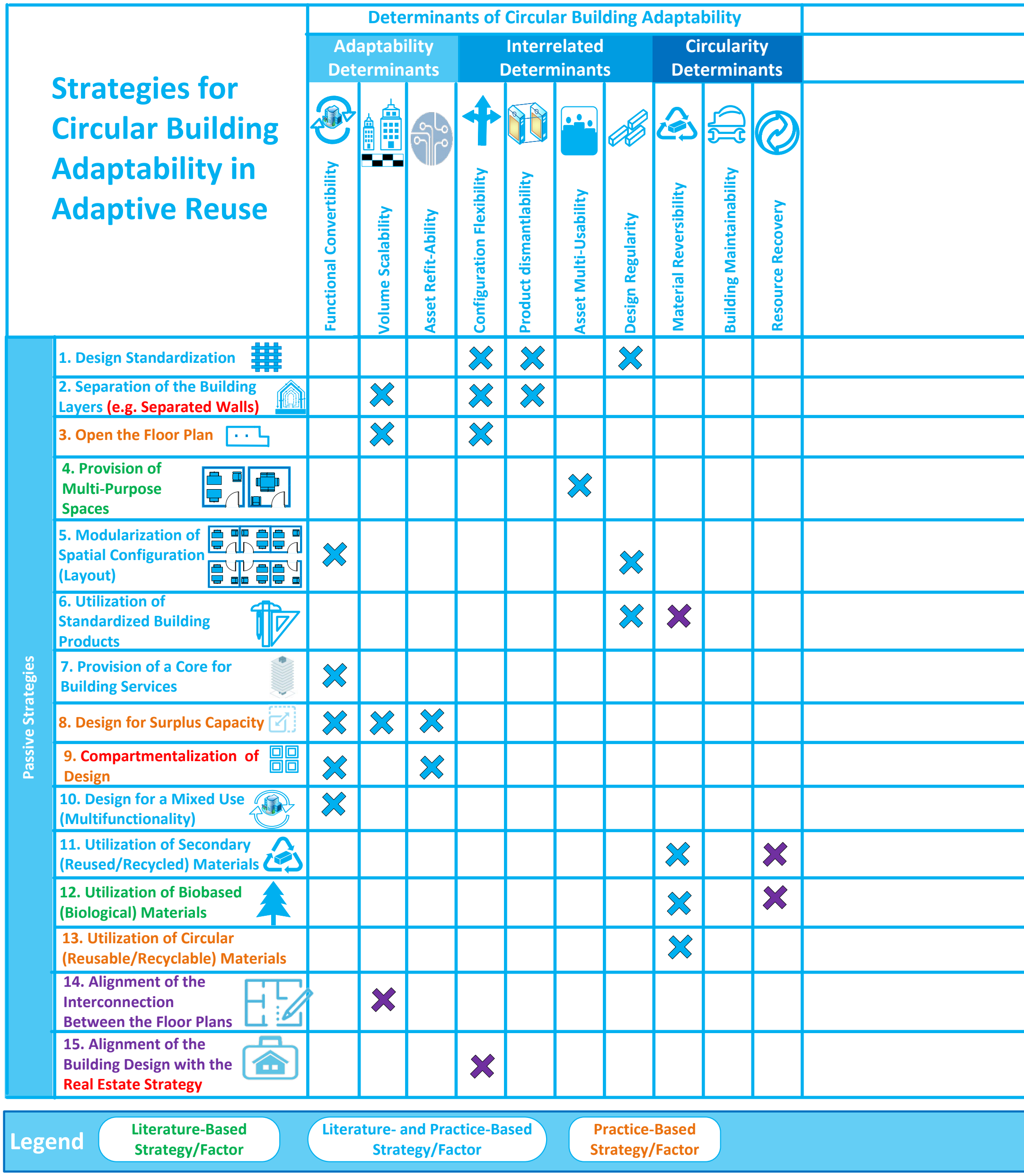
Determinant	Brief description
Configuration flexibility	The capacity to reconfigure the layout of spaces without utilizing external resources and producing waste.
Product dismantlability	The capacity to dismantle components and products in a building without inflicting damage and producing waste, so 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 maximizing the efficiency of their utilization
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 y 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, utilize 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 organization, 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: Chapter 3 (Hamida et al., 2023b)

The CBA determinants were defined based on critically analysing and resynthesizing concepts and models related to adaptability and circularity in the building environment (Akhimien *et al.*, 2021; Arge, 2005; Bettaieb and Alsabban 2021; Foster, 2020; Eberhardt *et al.*, 2022; Ellen MacArthur Foundation 2019; Geldermans, 2016; Heidrich *et al.*, 2017; Iyer-Raniga; 2019; Kyrö *et al.*, 2019; Slaughter, 2001; Pinder *et al.*, 2017). Therefore, the CBA determinants can be guiding when pursuing resource efficiency and long-lasting functionality in the built environment across different contexts other than building reuse (Ollár, 2024).

The enabling and inhibiting factors to implement these strategies are incorporated in the framework. The framework comprises 33 strategies, including 15 passive, 7 active, and 11 operational strategies, alongside 10 enablers and 7 inhibitors (Figure 5.2). Passive design strategies comprise solutions that can promote CBA through the building design, while active strategies encompass solutions that foster CBA through altering the building configuration and user intervention. Operational strategies are process-oriented solutions that promote CBA.

Content-wise, the CBA-AR framework is comprehensive, as it is based on previous literature reviews (Hamida *et al.* 2023a), empirical evidence from demonstration cases (Hamida *et al.* 2023b), and collaborative development and validation (Hamida *et al.* 2024). Usability-wise, the CBA-AR framework has been developed as a knowledge-based tool to help scholars and partitioners within the building and real estate fields in determining possible strategies for circular and adaptable building reuse (Hamida *et al.*, 2024). This can be realized by exploring the interconnection between the strategies and the CBA determinants – as a checklist, as well as the collective evaluation of the effectiveness, feasibility, and applicability of each strategy as shown in Figure 5.2. Generally, the practical contribution of this framework lies in its alignment with the EU Taxonomy compass (2020). In particular, the framework guides practitioners to consider key aspects mentioned in the EU Taxonomy Navigator (2020), namely design for resource efficiency, adaptability, flexibility, and disassembly to enable for reusability and recyclability of materials in renovating existing buildings. It also contributes to fostering circularity through design as a key accelerating player in the built environment (Greco *et al.*, 2024). However, how it can be used in practice as a tool has not been investigated yet, as pointed out by Hamida *et al.* (2024).



Strategies for Circular Building Adaptability in Adaptive Reuse		Determinants of Circular Building Adaptability									
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Passive Strategies	1. Design Standardization				✕	✕		✕			
	2. Separation of the Building Layers (e.g. Separated Walls)		✕		✕	✕					
	3. Open the Floor Plan		✕		✕						
	4. Provision of Multi-Purpose Spaces						✕				
	5. Modularization of Spatial Configuration (Layout)	✕						✕			
	6. Utilization of Standardized Building Products							✕	✕		
	7. Provision of a Core for Building Services	✕									
	8. Design for Surplus Capacity	✕	✕	✕							
	9. Compartmentalization of Design	✕		✕							
	10. Design for a Mixed Use (Multifunctionality)	✕									
	11. Utilization of Secondary (Reused/Recycled) Materials								✕		✕
	12. Utilization of Biobased (Biological) Materials								✕		✕
	13. Utilization of Circular (Reusable/Recyclable) Materials								✕		
	14. Alignment of the Interconnection Between the Floor Plans		✕								
	15. Alignment of the Building Design with the Real Estate Strategy				✕						

Legend: Literature-Based Strategy/Factor; Literature- and Practice-Based Strategy/Factor; Practice-Based Strategy/Factor

FIG. 5.2 The CBA-AR framework
Source: Chapter 4 (Hamida et al., 2024)

Enabling and Inhibiting Factors																	Evaluation of the Strategies			
Enabling Factors										Inhibiting Factors										
The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
✕	✖					✖					✕					✖	4	3	5	4
✕											✕	✖				✖	5	3	4	4
✕			✖								~~✕~~	✖			✖		4	3	3	3.3
✕			✖	✖							✕	✖			✖		4.5	3	4.5	4
✕	✖		✖			✖					~~✕~~	✖			✖		4.5	3	4	3.8
✕			✖								✕						3	4	4.5	3.8
✕											✕	✖					3	3	3	3
✕				✖			✖				✕	✖			✖		4	4	3	3.6
✕											✕	✖			✖		4	3	2	3
✕		✕	✖		✕		✖			✖	✖	✖	✕		✕		5	3	2	3.3
✕		✕	✕		✕			✖	✖	~~✕~~	✕	✕	✕	✕	✕	✖	5	2	1	2.6
✖		✖		✖				✖	✖	✖		✖			✕		4	3.5	2	3.1
✖	✕	✕		✖	✕			✖	✖	✕		✖	✕		✕		5	3.5	2	3.5
✖														✖			3	3	4	3.3
✖						✖											4	4	5	4.3

CO-Creation-Based Strategy/Factor

Co-Creation-Based ✖ Linking

Theory-Practice-Based ✕ Linking

Excluded Connection by ~~✕~~ Participants

Revised Text in Workshop 2

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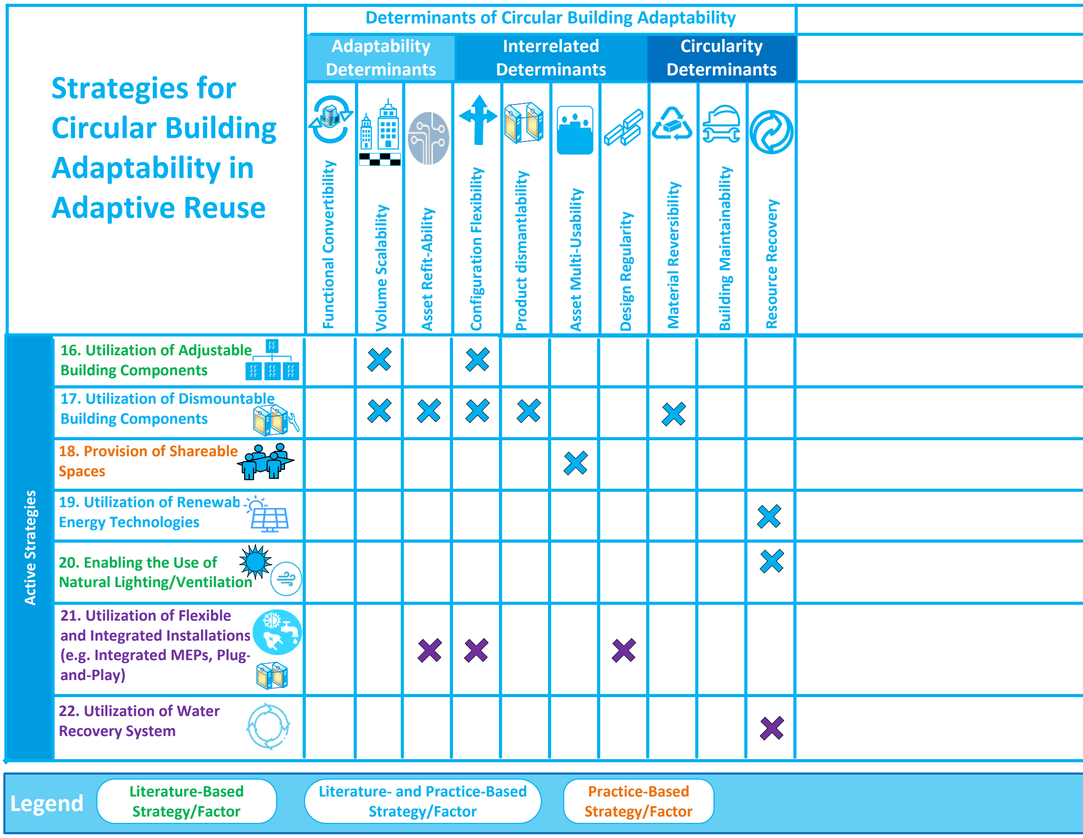

Strategies for Circular Building Adaptability in Adaptive Reuse		Determinants of Circular Building Adaptability									
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Active Strategies	16. Utilization of Adjustable Building Components		✕		✕						
	17. Utilization of Dismountable Building Components		✕	✕	✕	✕			✕		
	18. Provision of Shareable Spaces						✕				
	19. Utilization of Renewab Energy Technologies										✕
	20. Enabling the Use of Natural Lighting/Ventilation										✕
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)			✕	✕			✕			
	22. Utilization of Water Recovery System										✕

Legend: Literature-Based Strategy/Factor | Literature- and Practice-Based Strategy/Factor | Practice-Based Strategy/Factor

FIG. 5.2 The CBA-AR framework

Source: *Chapter 4* *(Hamida et al., 2024)*

	Enabling and Inhibiting Factors																	Evaluation of the Strategies			
	Enabling Factors										Inhibiting Factors										
	The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
	✖											✖	✖				✖	4	4.5	3	3.8
	✕	✖	✖									✕	✕			✕	✖	5	4.5	4.5	4.6
	✖				✖			✖		✖				✕		✖		3	3	5	3.6
	✖		✖				✕	✖	✖	✖			✖					3	5	5	4.3
	✖								✖				✖					4	3	4	3.6
												✖	✖				✖	4	5	5	4.6
									✖			✖	✖				✖	5	3	4	4

CO-Creation-Based Strategy/Factor

Co-Creation-Based ✖ Linking

Theory-Practice-Based ✕ Linking

Excluded Connection by ~~✕~~ Participants

Revised Text in Workshop 2

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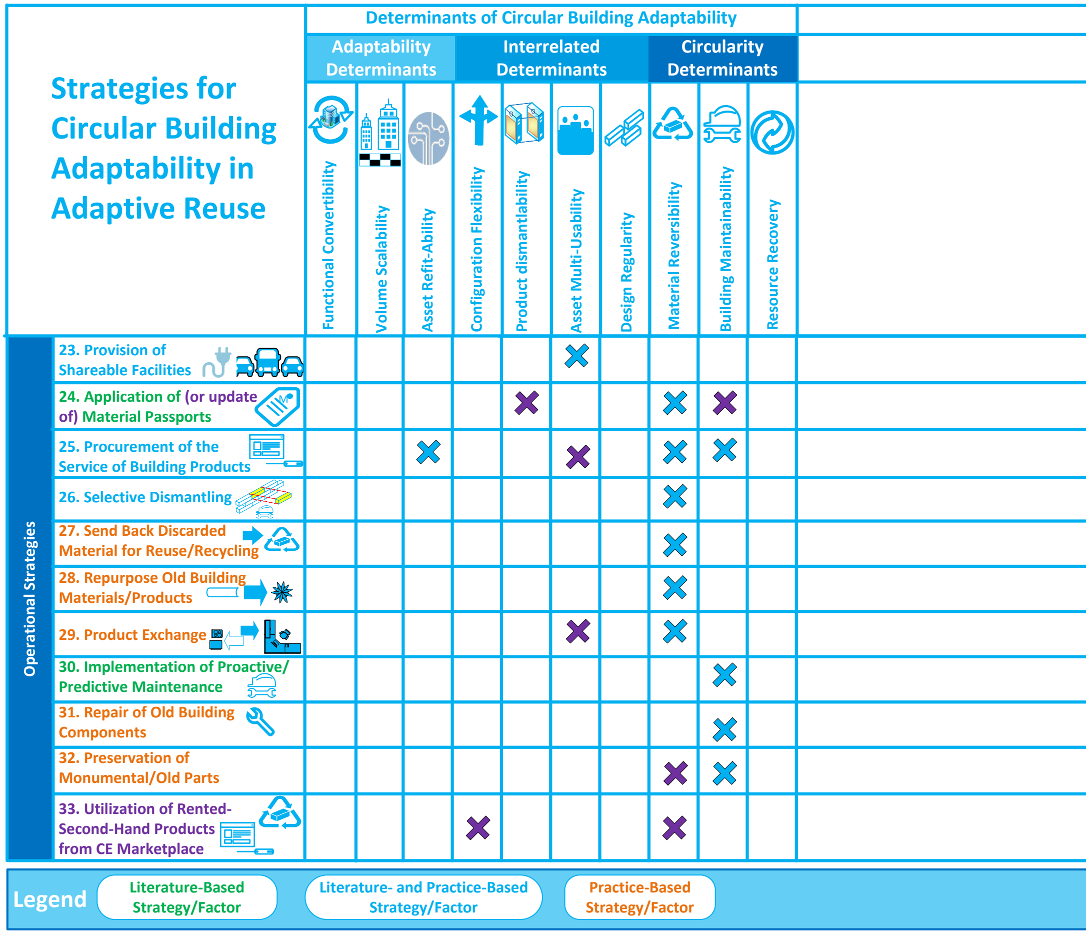


Strategies for Circular Building Adaptability in Adaptive Reuse		Determinants of Circular Building Adaptability									
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Operational Strategies	23. Provision of Shareable Facilities						✕				
	24. Application of (or update of) Material Passports					✖			✕	✖	
	25. Procurement of the Service of Building Products			✕			✖		✕	✕	
	26. Selective Dismantling								✕		
	27. Send Back Discarded Material for Reuse/Recycling								✕		
	28. Repurpose Old Building Materials/Products								✕		
	29. Product Exchange						✖		✕		
	30. Implementation of Proactive/ Predictive Maintenance									✕	
	31. Repair of Old Building Components									✕	
	32. Preservation of Monumental/Old Parts								✖	✕	
	33. Utilization of Rented-Second-Hand Products from CE Marketplace				✖				✖		

Legend: Literature-Based Strategy/Factor | Literature- and Practice-Based Strategy/Factor | Practice-Based Strategy/Factor

FIG. 5.2 The CBA-AR framework
Source: Chapter 4 (Hamida et al., 2024)

Enabling and Inhibiting Factors																	Evaluation of the Strategies			
Enabling Factors										Inhibiting Factors										
The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
	✕			✖	✖	✖	✖	✖	✖			✖					5	5	5	5
✖	✖	✖				✕		✖		✖	✖	✖	✕	✕	✖	✖	5	5	3	4.3
	✕			✕												✖	4	2.5	2	2.8
	✖	✖		✖	✖					✕	✕	✖	✕	✖	✕		5	2	2.5	3.2
	✕	✕		✕	✕			✖	✖	✖	✕	✖	✕	✖	✖		5	4	3	4
	✕	✕		✖	✖			✖	✖		✖	✕	✕	✖	✖	✖	5	4	2	3.6
	✕	✕		✖	✖	✖		✖	✖		✖	✖	✕	✖	✖	✖	5	2	3	3.3
				✕		✕				✕		✖		✖		✖	4	4.5	3	3.8
		✕		✖	✖					✕	✖	✖		✖		✖	4.5	4	4	4.2
✕		✕	✕								✕	✕		✕	✖		4.5	5	2	3.8
	✖	✖		✖		✖								✖	✖	✖	4.5	2	3.5	3.3

CO-Creation-Based Strategy/Factor

✖ Co-Creation-Based Linking

✕ Theory-Practice-Based Linking

~~✕~~ Excluded Connection by Participants

Revised Text in Workshop 2

5.5 An action- and design-research methodology to implement and test the usability and effectiveness of the CBA-AR framework

A mixed action research- and design research-oriented approach was followed in this chapter in line with Collatto *et al.*, (2018), as the overall focus of this study is on generating knowledge about the usability and effectiveness of an instrument in the real world. A reuse project of a vacant monumental office building to a multiple-office building – located in South Holland, the Netherlands – was used as a case project in this study (see subsection 3.2). Methodologically, the research methods were iteratively and sometimes simultaneously used to collect the data during a 5-month period– between April 2024 and September 2024 – as shown in Figure 5.3. Archival research, field observations and interventions, and reflection workshops were used as primary research methods. The iterative and simultaneous data collection logic was carried out, instead of a sequential logic, as indicated by Collatto *et al.*, (2018), due to the twofold aim of this study: testing and reflecting on the usability and effectiveness of the CBA-AR framework in practice. In this chapter, usability concerns all aspects of the ease of using the framework by practitioners, while effectiveness concerns the capacity of the framework to enhance the design outcomes for promoting CBA.

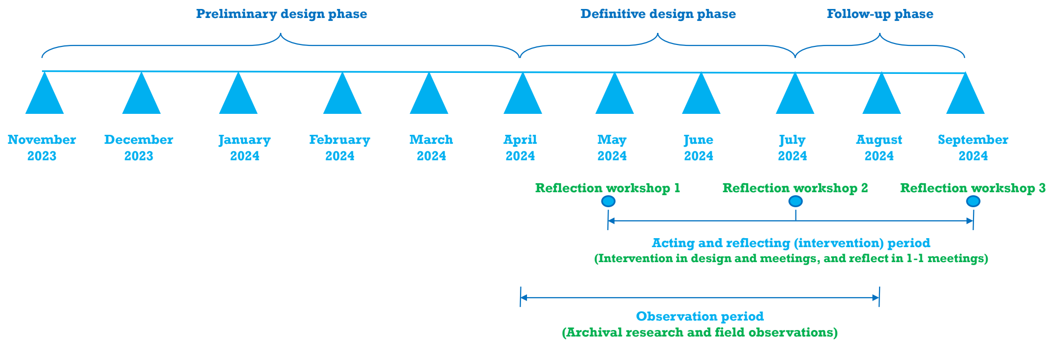


FIG. 5.3 Timeline and methods of observations, interventions, and reflections in this study

5.5.1 Background of action research and design research and their use in the methodology

Kemmis and McTaggart (1988) defined action research (AR) as “a form of collective self-reflective inquiry undertaken by participants in social situations in order to improve the rationality and justice of their own social or educational practices, as well as their understanding of these practices and the situations in which these practices are carried out.”. Such an approach has been recognized as a practically useful way of bringing research and practice together to deeply produce theoretical insights into a process or practice (Altrichter *et al.*, 2002). Based on Lewin’s (1946) description of the steps of action research, Kemmis and McTaggart (1988) described the process of action research as a series of self-reflective spirals (cycles) that follow the following sequence: planning, acting and observing, reflecting, and replanning and so on, respectively.

Action research can be conducted to serve different purposes. For instance, action research can be conducted for technical purposes to empower practitioners to improve the outcomes of practice. For instance, Alves et al. (2021) conducted an action research study to promote implementing an e-waste management program in São João del-Rei in Brazil and observe the outcomes of implementing the program in the city. Action research can be also carried out for practical purposes to enlighten practitioners and provide them with the education they need to act more wisely to improve the consequences and outcomes of a practice in the long term (Kemmis *et al.*, 2014). In this regard, researchers using AR-oriented approaches should pay close attention to the way of bridging the distance between academia and practice (Greco *et al.*, 2023).Recently, action research has been used as a valid approach to sustainable development-related studies by virtue of its potential to influence and transform policies and current practices (Keahey, 2021).

In this study, action research was incorporated into the research approach to bring about both technical and practical implications, as the aim of the study is to enable practitioners from the building industry and real estate market to actively promote CBA in building reuse projects through the use of a framework as a guiding tool.

Design research (DR) is characterized as a systematic approach that is concerned with the physical configuration and performance of human-made things, besides how the design process works (Bayazit, 2004). Archer (1981) defined DR as “systematic enquiry whose goal is knowledge of, or in, the embodiment of configuration, composition, structure, purpose, value and meaning in man-made things and systems.”, also shortly as a “systematic enquiry into the nature of design activity.”. In this regard, Frayling (1993) categorized DR into three forms, namely research into art and design – researching the practice of designing objects/processes, research through art and design – researching through developing design, and research for art and design – researching to serve design. These forms are interrelated and can be indispensable in some situations.

In the design-related fields, AR can be integrated with design and DR to facilitate knowledge creation, improving a certain situation, and solving a problem through a design practice of demonstrating or building a new thing (Collatto *et al.*, 2018; Goldkuhl, 2013). Combining AR with DR enables innovative design, while intervening, evaluating, and reflecting on the outcomes of process interventions (Sein *et al.*, 2011). AR and DR can also be brought together to apply and test a framework in the built environment design (see Gaete Cruz *et al.*, 2022; Pikas *et al.*, 2020).

In conclusion, this combination between AR and DR can facilitate research on process- and object-related themes, as shown in Figure 5.4. In the built environment, our AR- and DR- approach can be philosophically positioned within the so-called emancipationist philosophical perspective, owing to the epistemological (reality-related) and ontological (knowledge-related) assumptions (Salama, 2019).

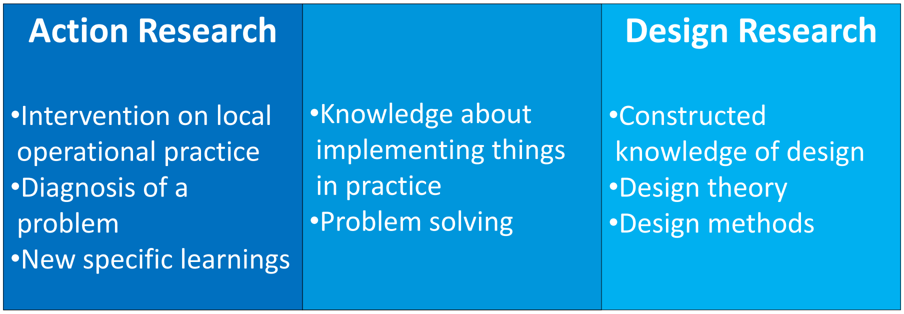


FIG. 5.4 Conceptual mapping of the potential outcomes of combining AR and DR
Source: Adapted from (Collatto et al., 2018; Goldkuhl, 2013)

5.5.2 Description of the case project

The used case in this study is a monumental office building in the Netherlands, built in 1907, that will be transformed into a multiple-office building by a real estate developer that acquired the building in 2021. Table 5.2 briefly summarizes the profile of the case project. Although this project is used as a single case to test and reflect on the usability and effectiveness of the CBA-AR framework, the outcomes of such one sample can be generalizable for three reasons. First, this study explores an emerging topic using multiple sources of evidence according to Yin (2009) (see sub-subsection 5.5.3). Second, the research methods were used iteratively, aligning with what Eisenhardt (1989) indicated about reaching saturation in case study research. Third, the project reuse process is unconventional – redevelopment of a listed cultural heritage asset – which can contribute to providing insights into other dynamics and relationships for drawing inferences based on rich field experiences as indicated by Sharma *et al.* (2024).

TABLE 5.2 Profile of the case project

Item	Value
Project previous use	Office building
Project new use	Multiple-offices building with co-working spaces
Year of construction	1907
Location	South Holland, NL
Land area	ca. 6,000 m^2
Gross floor area	ca 6,500 m^2
Lettable floor area	ca. 3,500 m^2
Number of floor plans	4 floors
Building use	Office
Construction systems and materials	Brick facade, steel structure, concrete slab, flat and pitched roofs, and a skylight.

Source: Created based on technical reports provided by the real estate developer

The building is a 4-story building with a gross floor area of 6,500 m^2, lettable floor area of 3,500 m^2, and land area of 6,000 m^2. The architectural style of the building is classic, as it was built using different types of typically local construction methods and materials, including a brick facade, steel structure, concrete slabs, and flat and pitched roofs.

This case project was selected due to its alignment with the focus of this study in two main respects. First, the project was about to enter the definitive design phase, during which key design decisions are typically made. Second, the project developer was willing to experiment with circular design and the use of the CBA-AR framework.

5.5.3 Data collection

This study iteratively used three methods: archival research, field observations and interventions, and reflection workshops. Table 5.3 provides an overview of the type of data collected in each method. Next follows a further explanation of these methods and their data.

TABLE 5.3 Research methods and their data

Method	Type	Number
Archival research	Design documents	2
	Technical reports	2
	Inventory sheets	4
Field observations and interventions	Design meetings	3
	Walkthrough audit	10
	Field inspections	3
	Reflection/follow-up meetings between the researchers and a practitioner	6
Workshops	Reflection workshop	3

Archival research

Archival research refers to reviewing or investigating various documents produced by organizations or individuals for using information produced in the past for specific research-oriented purposes (Ventresca and Mohr, 2002). In this study, the reviewed and investigated archives include design documents, technical reports, and inventory sheets (Table 5.3). These archival documents have been investigated to understand the project context and draw inferences about the possibility of implementing certain strategies during the observation and intervention periods.

The original as-built drawings and the ongoing definitive design proposals have been acquired, in a digital format, from the developer. These design documents have iteratively been used and investigated during the observation and intervention periods, along with the field observations and reflection workshops (see Figure 5.3). In addition, two technical reports were acquired, namely the project plan – issued by the real estate developer itself – and documentation of the building history – issued for the developer by an advisory organization specialized in advising and developing policies for preserving and restoring cultural heritage buildings in the Netherlands. Both technical reports were used during the observation and intervention periods as well. They effectively contributed to getting a better grasp on the context of the case project and building its profile. Finally, inventory sheets of the available building materials, products, and systems were developed as well as frequently updated and used in participation with the real estate developer during the intervention period.

Field observations and intervention

This method is a twofold ethnography-based technique that was used to observe, intervene, and reflect in action. The purposeful combination of ethnographic field study, incorporating participant observation and action research, positions the researcher in a unique setting to ground evidence in practice as shown in previous studies (see Jay, 2013; Greco and Long, 2022 for example studies). In this study, this technique was adopted and implemented by the first author who joined the developing team on the project site once a week between April 2024 and July 2024. During that period, data were collected by joining three design meetings between the developer and architect, conducting ten walkthrough audits during the weekly participation on site, joining the developer team in three field inspections with other stakeholders (including municipality, acoustical consultants, collateral heritage specialist, HVAC specialist, and fire safety department), and holding six 1-1 follow-up and reflection meeting with the developing manager. (Table 5.3). The CBA-AR framework was introduced to the developing team at the beginning of the observation period in a 1-1 meeting, which contributed to defining the CBA strategies that have already been implemented in the original design of the building

Aligning observation-, intervention- and reflection-related activities is a crucial step in action research-based studies (Postholm, 2020). Accordingly, the first author reported observations, interventions, and reflections every week for both on-site and remote work. The notes clearly make a distinction between planned and unplanned observations and interventions. The reported observations, interventions, and reflections were abductively processed, meaning that the possibility of emerging themes was considered along with the process of testing the CBA-AR framework – this study’s main theme and guiding scheme.

Abduction is a form of reasoning logic used for acquiring knowledge and drawing inferences about observed reality to generate, and properly test, new ideas, knowledge, and even theories based on empirical data and reasons without necessarily having presuppositions. Therefore, it enables researchers to freely and spontaneously acquire new knowledge based on observations from the real world without being neither limited to literature nor ignorant of it (Reichertz, 2014), which makes is it useful for case-based research (Dubois and Gadde, 2002).

Sub-subsection 3.4 provides further information about the data analysis and validation methods.

Reflection workshops

Three action- and-design-oriented reflection workshops were organized on the 21st of May 2024, the 9th of July 2024, and the 27th of September 2024, respectively. These workshops were held as milestones to collaboratively reflect back on the useability and effectiveness of the CBA-AR framework as a design guiding tool in the case project during the observation and intervention periods (Figure 5.3). Action research-wise, workshops can be incorporated into the phases of action research as short cycles of actively acting in or reflecting on a phenomenon of interest (Fisher, 2004; List, 2006). For instance, Aigwi *et al.* (2021) organized a workshop to collaboratively validate a developed process-oriented framework for an effective decision-making process in adaptive reuse projects. In design-related fields, workshops have been used as an effective method for designing and evaluating artifacts (Thoring *et al.*, 2020). For instance, van Stijn and Gruis (2020) conducted two design-oriented student workshops to apply and test a framework for developing circular building components. In addition, Gaete Cruz *et al.* (2022) facilitated three design workshops within an action research-oriented approach to practically apply a framework for the collaborative design of urban spaces.

In this study, these workshops served as brainstorming sessions to feed the design proposals. The program of the first two workshops included an activity of collaborative mapping of the utilized CBA strategies to the definitive design drawings. In this study, the methodological framework of Storvang *et al.* (2018) for planning, diagnosing, facilitating, and analyzing workshops as a research method was followed. Table 5.4 provides an overview of the protocol of the three workshops, including the purpose, roles and responsibilities, participants, and boundary objects in each workshop. During these workshops, the participants were allowed to express their perception of the actionable part of the study and were given the flexibility to use their terminologies to refer to their own experiences, thereby enhancing the credibility of the research. According to, Champion and Stowell, (2003) empowering participants in action research to express their judgment on the research inquiry and also giving them access to the research process are substantial for establishing the credibility and validity of AR.

Two members of the developing team – including the developing manager and a specialist in cultural heritage redevelopment – participated in the reflection workshops, as project representatives with a design background, along with three to four authors, as action researchers. Regarding the workshop facilitators, the first author – who has hands-on the project – moderated the three workshops along with the fourth author. The other authors were active participants, iteratively checking taken actions in real-time while also reflecting on the usability and effectiveness of the CBA-AR framework and design outcomes. The CBA-AR framework along with the drawings of the definitive design were the key boundary objects in the first two workshops. In the second workshop, the outcome of reflecting on the useability of the framework – a compiled prescriptive booklet as a prototype – was a boundary object to the outcomes of workshop 1 regarding the strategies that were perceived as possible. In the final workshop, the focus was mainly on the finalized improvements of the framework, so the digitized prototype – a platform – was the main boundary object. Table 5.4 demonstrates the specific differences in the purpose, responsibilities boundary objects among the three workshops.

TABLE 5.4 Protocol of the three reflection workshops

Workshop	Purpose	Roles and responsibilities	Boundary objects
Workshop 1	Reflecting on the usability and effectiveness of the first version of the CBA-AR framework as well as the implementation of the CBA strategies in the definitive design proposal	**Facilitators:** Moderating the workshop as well as observing and reporting the outcomes **Researchers:** Reflecting on the design outcomes and framework usability **Participants**: Defining the implemented CBA strategies and other possible strategies for implementation in the project, as well as reflecting on the usability and effectiveness of the framework	• Version 1 of the CBA-AR framework. • Definitive design drawings. • Presentation about the project profile.
Workshop 2	Reflecting on the usability and effectiveness of the revised version of the CBA-AR framework and its prescriptive booklet as well as a series of CBA strategies that were perceived as possible in workshop 1	**Facilitators:** Moderating the workshop as well as observing and reporting the outcomes **Researchers:** Reflecting on the outcomes of workshop 1, the possibility of easing the implementation of a series of perceived strategies possible in workshop 1, and the usability of the revised version of the framework and its prescriptive (user) booklet. **Participants**: Reflecting on the outcomes of workshop 1, the possibility of easing the implementation of a series of perceived strategies as possible in workshop 1, and the usability of the revised version of the framework and its prescriptive (user) booklet	• Version 2 of the CBA-AR framework (embedded in a compiled prescriptive user booklet). • Definitive design drawings. • Summary of outcomes of workshop 1.
Workshop 3	Reflecting on the usability and effectiveness of the finalized and digitized versions of the CBA-AR framework (including its prescriptive guide)	**Facilitators:** Moderating the workshop as well as observing and reporting the outcomes **Researchers:** Reflecting on the outcomes of workshop 2, the usability of the revised and digitized version of the framework (including its user guide), and the research conclusion **Participants**: Reflecting on the outcomes of workshop 2 and the usability of the revised and digitized version of the framework (including its user guide)	Version 3 of the CBA-AR framework (embedded in a developed platform)

5.5.4 Data analysis and validation

The collected data were immediately analyzed and interpreted abductively. The components of CBA-AR framework (Hamida *et al*. 2024) were used as a coding scheme while spontaneously enabling other themes to emerge from the observations.

To uphold the construct validity of this study, the collected data were validated by adhering to two principles of validity of AR data, namely *reflexivity* and *dialectics*. *Reflexivity* in AR is related to the main philosophy of AR in which researchers would have reflective thinking and consciously reflect on their experience about interaction with the participants along with the epistemological and ontological assumptions, while *dialectics* refers to the consideration of different voices through facilitating interactive discussions and interpretations during the conduct and reporting of AR (Heikkinen *et al*., 2012).

In this study, *reflexivity* was established by maintaining an ongoing reflection on the collected data from the archival research, observations, interventions in the field, and reflection workshops. The analyzed data from the archival research was reported by the first author and discussed with the developing manager in some 1-1 meetings. The reported observations and interventions along with the reflections were shared with the other authors as other interpreters. The outcomes of each reflection workshop were analyzed, reported, and shared with the participants and the other authors for reflection in real-time. *Dialectics* was fulfilled by engaging and bringing together the authors – as action researchers – and members of the developing team – as practitioners – in the workshops and empowering them to reflect together on the amendment of the CBA-AR framework and the research progress in general.

5.6 Findings

This study focuses on bridging the gap between the theory and practice of adaptive reuse by testing and reflecting on the useability and effectiveness of utilizing the CBA-AR framework as a guiding tool in practice. Therefore, this section presents the results of this twofold test followed by other outcomes that emerged through the study. In general, the descriptive version of the CBA-AR framework (Figure 5.2) was perceived as an informative tool at the beginning of the observation and intervention period. However, it was perceived as a complicated tool that needed a simplified general explanation on one hand, and further elaboration, description, and practical examples of its content on the other hand.

5.6.1 Examination of the usability of the framework

As the ease of using the framework is a key determinant of its usability, the findings of the first two rounds of iteration contributed to refining the framework and making it easier to use. Introducing the framework to the developing manager contributed to defining 18 CBA strategies already implemented in the project and considered in the initial definitive design proposals, which has been a useful mapping exercise. Following are the eleven strategies along with their practical applications:

- **Design standardization:** Acoustical installations.
- **Separation of the building layers:** The partitions are designed for a lifespan of 20-25 years, while the fit-outs will be considered to last for 10-15 years.
- **Open the floor plan:** The main hall (in the original design).
- **Provision of multi-purpose spaces:** The hall is a multi-use space.
- **Modularization of spatial configuration:** Modular layout of spaces.
- **Provision of a core for building services:** Two cores for stairs, MEPs shafts, and toilets.
- **Compartmentalization of design:** Compartmentalizing the building. horizontally, meaning that each floor is a compartment on its own.
- **Utilization of biobased materials:** Timber, wooden studs, and biobased paintings.
- **Utilization of reusable products:** Removable partitions.
- **Alignment of the interconnection between the floor plans:** Placing all the plumbing services in two shafts in the same location on each floor.

- **Alignment of the building design with the real estate strategy:** Preserving the heritage assets in the building within the redevelopment process while diversifying the users (type of tenants) in the building.
- **Provision of shareable spaces:** A shareable hall, toilets, and meeting rooms
- **Enable the use of natural lighting and ventilation:** All offices have windows that can be opened.
- **Provision of shareable facilities:** Shareable charging stations and pantries.
- **Send back old materials for reuse:** Glass panels.
- **Implementation of proactive/predictive maintenance:** Adoption of multi-year maintenance plan.
- **Repair of old building components:** Façade renovation.
- **Preservation of monumental parts:** Preserving closets, chandeliers, busts, and old radiators in the hall and stairs as well as on the ground floor.

In the first reflection workshop, the participants pointed out that the descriptive framework (Figure 5.2) can be used as a checklist tool (see Appendix F). In contrast, they concluded that it needs further improvements, namely simplifying its description, elaborating on the strategies – specifically by adding a description, practical examples, phase of implementing, advantages and disadvantages of each strategy, and aligning the CBA strategies with the shearing layers model by Brand (1994). Furthermore, they concluded that the framework outline should be described in a simplified manner. Some textual amendments were recommended too; for example, reformulating ‘product dismantlability’ to ‘building demountability’ to ease its comprehension by the framework users.

Accordingly, the framework has been revised in line with the inputs in the first round of observing, intervening, and reflecting. A prescriptive user booklet was compiled – as a first user-oriented prototype – and shared with the participants to ease the framework’s usability. The booklet contains three main sections: an overview, a description of the strategies, and a user guide. The second section includes an in-depth description of the CBA strategies, while the third section includes a newly designed approach and worksheet for the user (see sub-subsection 5.6.3).

In the second reflection workshop, the participants reflected on the revised CBA-AR framework (Figure 5.5) and the compiled prescriptive use booklet, preceded by a discussion on the potential to implement another 12 strategies in the definitive design of the project. The participants proposed rephrasing 4 strategies (No. 11, 13, 16, and 31) as well as mapping the strategies to the R-ladder model by Potting *et al.* (2017) as another circularity-oriented measure. In addition, the participants emphasized the need to digitize the framework in a user-friendly way.

Accordingly, between the last two workshops, the R-ladder model was incorporated into the framework and mapped to the CBA strategies as a proxy for the actual measurements of circularity. Then, a platform was established as a digitally accessible prototype of the framework. In the third workshop, the participants reflected on the useability of this platform and recommended minor improvements to further enhance its user-friendliness.

	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability									
						Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
						Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Passive Strategies	1. Design Standardization	Design	S4, S5. S6	Consisted use of walls, doors and windows	R2				✖	✖		✖			
	2. Separation of the Building Layers (e.g. Separated Walls)	Design	S3, S4, S5, S6	Partitions are independents connected by dry connections	R2		✖		✖	✖					
	3. Open the Floor Plan	Design	S5	Open office space	R2		✖		✖						
	4. Provision of Multi-Purpose Spaces	Design	S5	Spaces that can be used as offices and meeting rooms	R1						✖				
	5. Modularization of Spatial Configuration (Layout)	Design	S4, S5	Unitized and repetitive pattern of rooms	R2	✖						✖			
	6. Utilization of Standardized Building Products	Design	S4, S5. S6	Using standardized doors, ceilings and partitions throughout the building	R2							✖	✘		
	7. Provision of a Core for Building Services	Design	S5	Central area providing an elevator and a shaft	R2	✖									
	8. Design for Surplus Capacity	Design	S3, S4, S5	Oversizing spaces and systems	R1 and R0	✖	✖	✖							
	9. Compartmentalization of Design	Design	S4, S5	The building is divided into independent zones	R1	✖		✖							
	10. Design for a Mixed Use (Multifunctionality)	Design	S3, S4, S5, S6	The building includes and can accommodate different function	R1	✖									
	11. Utilization of Secondary (Reused/ Recycled) Materials Product	Design	S4, S5. S6	Using second hand furniture	R3 and R8								✖		✘
	12. Utilization of Biobased (Biological) Materials	Design	S3, S4, S5. S6	Using timber-based products	R2								✖		✘
	13. Utilization of Circular (Reusable/Recyclable) Materials/Products	Design	S3, S4, S5. S6	Glass panels can be reused and recycled at the end of their use	R2								✖		
	14. Alignment of the Interconnection Between the Floor Plans	Design	S5	Horizontal zones are vertically coordinated with other zones through circulation means	-		✘								
	15. Alignment of the Building Design with the Real Estate Strategy	Design	S5	The building horizontal zones are coordinated with other zones	-				✘						

Legend Literature-Based Strategy/Factor | Literature- and Practice-Based Strategy/Factor | Practice-Based Strategy/Factor | CO-Creation-Based Strategy/Factor | Co-Creation-Based ✘ Linking

FIG. 5.5 The revised version of the framework based on the first two rounds of observing and intervening

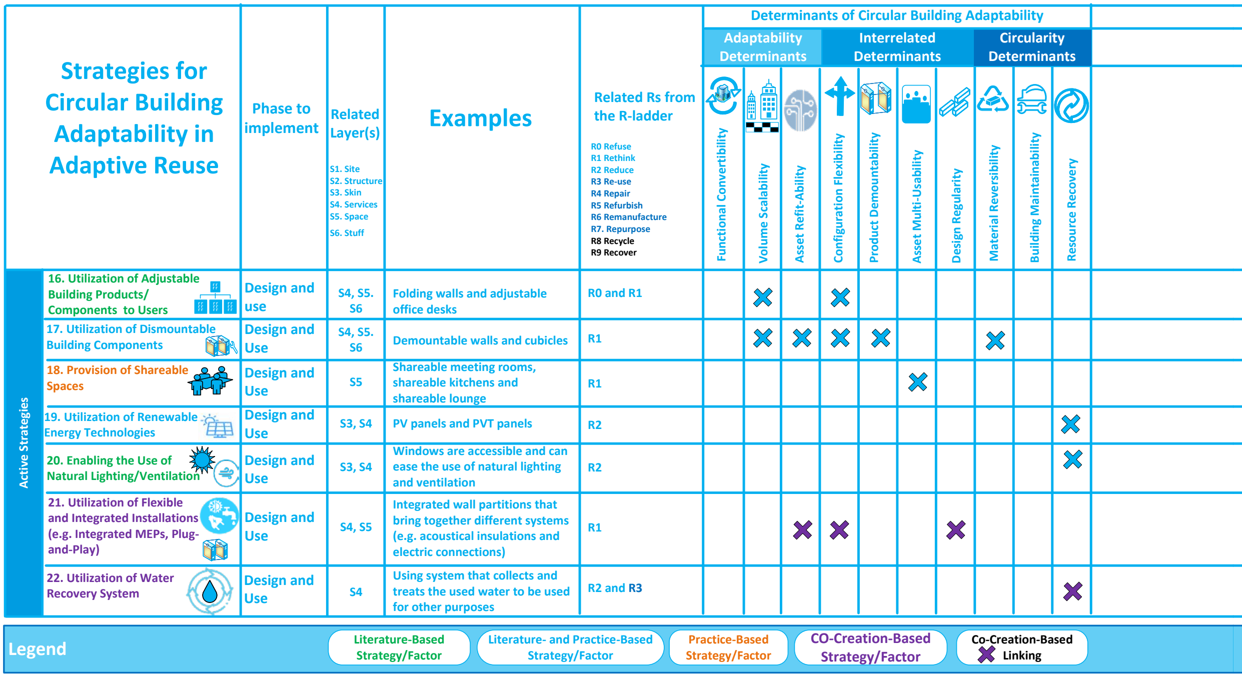
	Enabling and Inhibiting Factors																	Evaluation of the Strategies			
	Enabling Factors										Inhibiting Factors										
	The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
	✕	✖					✖					✕					✖	4	3	5	4
	✕											✕	✖				✖	5	3	4	4
	✕			✖									✖			✖		4	3	3	3.3
	✕			✖	✖							✕	✖			✖		4.5	3	4.5	4
	✕	✖		✖			✖						✖			✖		4.5	3	4	3.8
	✕			✖								✕						3	4	4.5	3.8
	✕											✕	✖					3	3	3	3
	✕				✖			✖				✕	✖			✖		4	4	3	3.6
	✕											✕	✖			✖		4	3	2	3
	✕		✕	✖		✕		✖			✖	✖	✖	✕		✕		5	3	2	3.3
	✕		✕	✕		✕			✖	✖		✕	✕	✕	✕	✕	✖	5	2	1	2.6
	✖		✖		✖				✖	✖	✖		✖			✕		4	3.5	2	3.1
	✖	✕	✕		✖	✕			✖	✖	✕		✖	✕		✕		5	3.5	2	3.5
	✖														✖			3	3	4	3.3
	✖						✖											4	4	5	4.3

Theory-Practice-Based ✕ Linking

R0- R2 = Smarter product use and manufacture

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials



	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability									
						Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
						Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Active Strategies	16. Utilization of Adjustable Building Products/ Components to Users	Design and use	S4, S5. S6	Folding walls and adjustable office desks	R0 and R1		✖		✖						
	17. Utilization of Dismountable Building Components	Design and Use	S4, S5. S6	Demountable walls and cubicles	R1		✖	✖	✖	✖			✖		
	18. Provision of Shareable Spaces	Design and Use	S5	Shareable meeting rooms, shareable kitchens and shareable lounge	R1						✖				
	19. Utilization of Renewable Energy Technologies	Design and Use	S3, S4	PV panels and PVT panels	R2										✖
	20. Enabling the Use of Natural Lighting/Ventilation	Design and Use	S3, S4	Windows are accessible and can ease the use of natural lighting and ventilation	R2										✖
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)	Design and Use	S4, S5	Integrated wall partitions that bring together different systems (e.g. acoustical insulations and electric connections)	R1			✖	✖			✖			
	22. Utilization of Water Recovery System	Design and Use	S4	Using system that collects and treats the used water to be used for other purposes	R2 and R3										✖

Legend

Literature-Based Strategy/Factor

Literature- and Practice-Based Strategy/Factor

Practice-Based Strategy/Factor

CO-Creation-Based Strategy/Factor

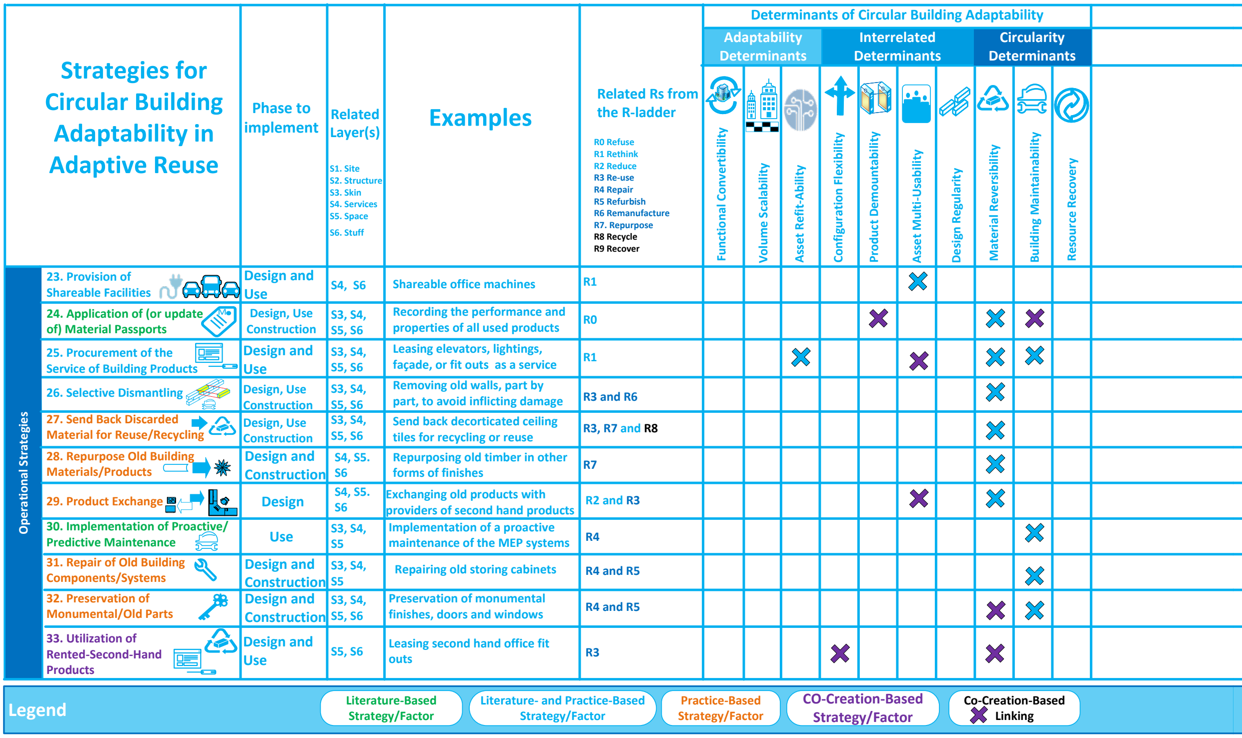
Co-Creation-Based ✖ Linking

FIG. 5.5 The revised version of the framework based on the first two rounds of observing and intervening

	Enabling and Inhibiting Factors																	Evaluation of the Strategies			
	Enabling Factors										Inhibiting Factors										
	The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
	✖											✖	✖				✖	4	4.5	3	3.8
	✕	✖	✖									✕	✕			✕	✖	5	4.5	4.5	4.6
	✖				✖			✖		✖				✕		✖		3	3	5	3.6
	✖		✖				✕	✖	✖	✖			✖					3	5	5	4.3
	✖								✖				✖					4	3	4	3.6
												✖	✖				✖	4	5	5	4.6
									✖			✖	✖				✖	5	3	4	4

Theory-Practice-Based ✕ Linking | R0- R2 = Smarter product use and manufacture | R3- R7 = Extend life of product and its parts | R8- R9 = Useful application of materials

TOC



	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	Determinants of Circular Building Adaptability									
						Adaptability Determinants			Interrelated Determinants				Circularity Determinants		
						Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery
Operational Strategies	23. Provision of Shareable Facilities	Design and Use	S4, S6	Shareable office machines	R1						✕				
	24. Application of (or update of) Material Passports	Design, Use Construction	S3, S4, S5, S6	Recording the performance and properties of all used products	R0					✕			✕	✕	
	25. Procurement of the Service of Building Products	Design and Use	S3, S4, S5, S6	Leasing elevators, lightings, façade, or fit outs as a service	R1			✕			✕		✕	✕	
	26. Selective Dismantling	Design, Use Construction	S3, S4, S5, S6	Removing old walls, part by part, to avoid inflicting damage	R3 and R6								✕		
	27. Send Back Discarded Material for Reuse/Recycling	Design, Use Construction	S3, S4, S5, S6	Send back decorticated ceiling tiles for recycling or reuse	R3, R7 and R8								✕		
	28. Repurpose Old Building Materials/Products	Design and Construction	S4, S5. S6	Repurposing old timber in other forms of finishes	R7								✕		
	29. Product Exchange	Design	S4, S5. S6	Exchanging old products with providers of second hand products	R2 and R3						✕		✕		
	30. Implementation of Proactive/ Predictive Maintenance	Use	S3, S4, S5	Implementation of a proactive maintenance of the MEP systems	R4									✕	
	31. Repair of Old Building Components/Systems	Design and Construction	S3, S4, S5	Repairing old storing cabinets	R4 and R5									✕	
	32. Preservation of Monumental/Old Parts	Design and Construction	S3, S4, S5, S6	Preservation of monumental finishes, doors and windows	R4 and R5								✕	✕	
	33. Utilization of Rented-Second-Hand Products	Design and Use	S5, S6	Leasing second hand office fit outs	R3				✕				✕		

Legend

Literature-Based Strategy/Factor

Literature- and Practice-Based Strategy/Factor

Practice-Based Strategy/Factor

CO-Creation-Based Strategy/Factor

Co-Creation-Based ✕ Linking

FIG. 5.5 The revised version of the framework based on the first two rounds of observing and intervening

Enabling and Inhibiting Factors																	Evaluation of the Strategies			
Enabling Factors										Inhibiting Factors										
The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
	✕			✖	✖	✖	✖	✖	✖			✖					5	5	5	5
✖	✖	✖				✕		✖		✖	✖	✖	✕	✕	✖	✖	5	5	3	4.3
	✕			✕												✖	4	2.5	2	2.8
	✖	✖		✖	✖					✕	✕	✖	✕	✖	✕		5	2	2.5	3.2
	✕	✕		✕	✕			✖	✖	✖	✕	✖	✕	✖	✖		5	4	3	4
	✕	✕		✖	✖			✖	✖		✖	✕	✕	✖	✖	✖	5	4	2	3.6
	✕	✕		✖	✖	✖		✖	✖		✖	✖	✕	✖	✖	✖	5	2	3	3.3
				✕		✕				✕		✖		✖		✖	4	4.5	3	3.8
		✕		✖	✖					✕	✖	✖		✖		✖	4.5	4	4	4.2
✕		✕	✕								✕	✕		✕	✖		4.5	5	2	3.8
	✖	✖		✖		✖								✖	✖	✖	4.5	2	3.5	3.3

Theory-Practice-Based ✕ Linking

R0- R2 = Smarter product use and manufacture

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

TOC

5.6.2 Examination of the framework effectiveness

In this study, the effectiveness of the CBA-AR framework refers to its capacity to enhance the design for CBA promotion. The developing team of the project, in collaboration with other collaborators and the researcher, has been able to expand 4 out of the 18 strategies mentioned in sub-subsection 5.6.1, and also incorporate another new 6 strategies into the definitive design, effectively amounting to a total of 24 strategies considered for implementation in the project. Following is an elaboration on the expanded 4 strategies:

- **Design standardization:** Standardized wall panels and acoustical installations
- **Send back discarded materials for reuse/recycling:** Old glass panels from the façade have been sent for reuse, whereas old lighting fixtures and ceiling tiles have been considered to be sent for reuse
- **Repair of old building components:** Repairing old radiators and refurbishing old wall panels.
- **Preservation of monumental parts:** Preserving closets, chandeliers, busts, and old radiators in the hall and stairs as well as on the ground floor.

The following are the 6 newly added strategies to be considered for implementation in the case project:

- **Utilization of standardized building products:** Standardized partitions
- **Utilization of second-hand (reused/recycled) materials/products:** Using second-hand fit-outs on the first floors.
- **Utilization of adjustable building components/products:** Using some adjustable cubicles and office fit-outs
- **Utilization of demountable building components:** Old demountable partitions – made of gypsum board – will be reused on the second floor. New demountable wooden partitions will be used on the ground floor.
- **Selective dismantling:** Removing all partitions, ceiling tiles, vaults, and lighting fixtures systematically in a manner that would not cause damage.

- **Repurpose old building materials/products:** Wooden ceilings have been considered to be reused in the reception while vaults have been considered for reuse as cabinets.

Using the CBA-AR framework has enabled the identification of the enabling and inhibiting factors of the CBA strategies within the context of the case project. The intrinsic motivation of the developing team was a key enabler for paving the way for implementing the aforementioned strategies. On the other hand, there were many challenges for implementing many of the strategies in the project, namely physical – e.g. deterioration of the old building assets; information availability-related – e.g. lack of a record on the building assets, and economic - e.g. high investment costs. Below follows an elaboration on the inhibiting factors for other CBA strategies that were deemed impossible to implement in the project:

- **Design for surplus capacity:** The structure of the building was already designed for surplus capacity through its double-height ground floor and a high-strength steel structure. This overcapacity has already been used by the previous owner by adding a floor between the ground and the first floor and a third floor on the roof.

- **Design for mixed-use:** This strategy was impossible in the project because of a certain agreement between the developer and the original owner of the land.

- **Utilization of renewable energy technologies:** Solar PV panels have been considered, yet financial constraints on the project budget have been an obstacle to their use. However, future market research on cooperative solutions could take place during the detailed design phase afterward

- **Utilization of flexible and integrated installations:** During the design process, the team considered using plug-and-play (PNP) office booths and call cabinets that bring together lighting and electrical receptacles. However, their incompatibility with the sprinkler system – as a mandatory safety requirement – hindered the use of this kind of product in the building.

- **Utilization of water recovery system:** In the first workshop, it was concluded that using a water recovery system is impossible due to the configuration and composition of the monumental floorings of the building.

- **Application of material passports:** This strategy was seen as impossible due to financial constraints on the project budget, though it was perceived as effective by the participants in workshop 1.

- **Procurement of the service of building products:** Providing the new elevator as a service was considered as the net present value (NPV) comparison with owning a new elevator pointed out its feasibility for a service life of 20 years. However, the limited number of providers for this type of elevator raised concerns among the developing team regarding the viability of the service.

- **Product exchange:** The researcher and the developing team have reached out to several providers of second-hand building products and materials during the observation and intervention period to exchange the these providers. However, in workshop 2, it was concluded that such kind of exchange has been difficult and time- and product-specific, so it might be carried out with the projects of the developing organization.

- **Utilization of rented-second-hand products:** This strategy has been considered to be implemented for office booths; however, the developing team excluded that in workshop 2 due to quality- and cost-related reasons as it was concluded, based on market research, that they are economically less feasible and the quality is not insured in comparison with the case of renting new office fit-outs.

The framework was perceived as informative as a method for spontaneous screening. However, the participants requested additional clarification and elaboration on how it could be utilized as an indicative and assessment tool to enhance the decision on selecting strategies. More specifically, in the first workshop, the participants indicated that there is a need to have a measurable impact within the CBA-AR framework, along with practical examples. To bridge the distance between the descriptive nature of the framework and the need to make it more effective in practice, a user-prescriptive booklet was compiled to include further content, instruments, and instructions to enhance its effectiveness (see sub-subsection 5.6.3 and Appendix G).

To conclude, the effectiveness of the framework can be enhanced by providing further informative, exemplary, and guiding content along with indicative measures of the impact of the CBA strategies.

5.6.3 Improvement of the usability and effectiveness of the framework

Based on the results of testing and reflecting on the usability and effectiveness of the CBA-AR framework during the first three rounds of iterations (see sub-subsections 5.6.1 and 5.6.2), it was concluded that both qualities could be concluded by adding further explanatory, guiding, and assessment-oriented contents to the framework. Several actions have been taken, namely simplifying the framework description, compiling a user guide, and establishing a platform.

Simplification of the framework description

First, to simplify the description of the CBA-AR framework and the interconnection among its components, Figure 5.6 demonstrates the components of the framework brought together under four blocks: quality-related aspects, solution-related aspects, contextual aspects, and possibility-related aspects. The quality-related aspects are “what” related, as they provide indicative attributes and characteristics of circularity and adaptability They include the CBA determinants and the R-Ladder model according to Potting *et al.*, (2017). The solution-related aspects are “how” related and they mainly relate to the strategies, including examples, phase of implementation, and the corresponding building layers according to the shearing layers model by Brand (1994). The context-related aspects relate to the factors that could facilitate or impede the implementation of the CBA strategies. Finally, the possibility-related aspects relate to the applicability, effectiveness, and feasibility of the CBA strategies.

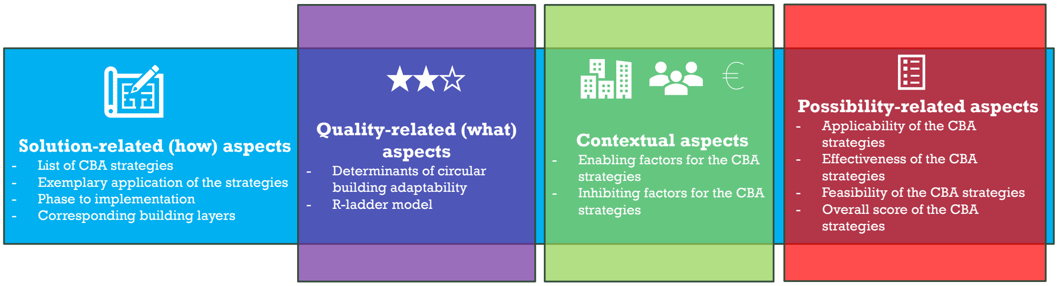


FIG. 5.6 A simplified visualized description of the 4 blocks bringing together the framework components

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It is worth noting that the description and visualization of the framework components have been revised on a continuous basis during the different rounds of reflection.

A user booklet

Second, a user booklet was compiled between the first and second rounds of reflection to provide practitioners with three facilitating resources: a simplified elaboration on the framework structure (See Figure 5.6), an in-depth description of the CBA strategies (Appendix G), and a usable tool. Previous research has shown that providing users of a certain product or a service with a guidance document (e.g., a handbook or a booklet) has proven effective and useful in cases where there is a gap or disconnect between user behavior and the intended use of a product or a service (Akasaka *et al.*, 2020; Watson, 2015).

The usable tool is a worksheet integrated and aligned with the CBA strategies through a stepwise iterative approach to simultaneously enhance the usability and effectiveness of the CBA-AR framework in practice. Figure 5.7 presents the developed stepwise approach for using the CBA-AR framework as a guiding, assessment, and reporting instrument, while Figure 5.8 presents the adapted worksheet. The content of the booklet has been improved and revised between the second the third rounds of reflection. Adapting a worksheet and a stepwise approach to facilitate the adoption of new methods in practical contexts was inspired by some examples in the literature (see McKenna *et al.* 2017; Hassanain *et al.* (2022).

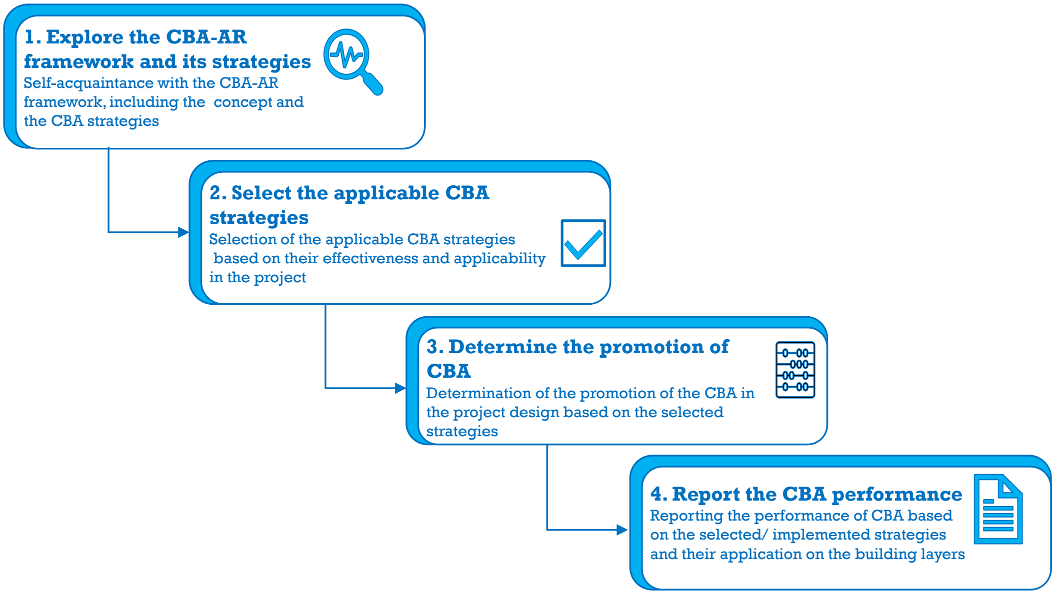

FIG. 5.7 A 4-stepwise approach for using the CBA-AR framework as a guiding, assessment, and reporting instrument

	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	
Passive Strategies	1. Design Standardization	Design	S4, S5. S6	Consisted use of walls, doors and windows	R2	
	2. Separation of the Building Layers (e.g. Separated Walls)	Design	S3, S4, S5, S6	Partitions are independents connected by dry connections	R2	
	3. Open the Floor Plan	Design	S5	Open office space	R2	
	4. Provision of Multi-Purpose Spaces	Design	S5	Spaces that can be used as offices and meeting rooms	R1	
	5. Modularization of Spatial Configuration (Layout)	Design	S4, S5	Unitized and repetitive pattern of rooms	R2	
	6. Utilization of Standardized Building Products	Design	S4, S5. S6	Using standardized doors, ceilings and partitions throughout the building	R2	
	7. Provision of a Core for Building Services	Design	S5	Central area providing an elevator and a shaft	R2	
	8. Design for Surplus Capacity	Design	S3, S4, S5	Oversizing spaces and systems	R1 and R0	
	9. Compartmentalization of Design	Design	S4, S5	The building is divided into independent zones	R1	
	10. Design for a Mixed Use (Multifunctionality)	Design	S3, S4, S5, S6	The building includes and can accommodate different function	R1	
	11. Utilization of Secondary (Reused/Recycled) Materials/Products	Design	S4, S5. S6	Using second hand furniture	R3 and **R8**	
	12. Utilization of Biobased (Biological) Materials	Design	S3, S4, S5. S6	Using timber-based products	R2	
	13. Utilization of Circular (Reusable/Recyclable) Materials/Products	Design	S3, S4, S5. S6	Glass panels can be reused and recycled at the end of their use	R2	
	14. Alignment of the Interconnection Between the Floor Plans	Design	S5	Horizontal zones are vertically coordinated with other zones through circulation means	-	
	15. Alignment of the Building Design with the Real Estate Strategy	Design	S5	The building horizontal zones are coordinated with other zones	-	

Legend

R0- R2 = Smarter product use and manufacture

FIG. 5.8 A worksheet for exploring, determining, assessing, and reporting the promotion of CBA in building reuse

Note: Yellow fields must be filled out by the user, if applicable

Determinants of Circular Building Adaptability														
Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
			✕	✕		✕					▨			
	✕		✕	✕										
	✕		✕								▨	▨		▨
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R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	
Active Strategies	16. Utilization of Adjustable Building Products/ Components to Users	Design and use	S4, S5. S6	Folding walls and adjustable office desks	R0 and R1	
	17. Utilization of Dismountable Building Components	Design and Use	S4, S5. S6	Demountable walls and cubicles	R1	
	18. Provision of Shareable Spaces	Design and Use	S5	Shareable meeting rooms, shareable kitchens and shareable lounge	R1	
	19. Utilization of Renewable Energy Technologies	Design and Use	S3, S4	PV panels and PVT panels	R2	
	20. Enabling the Use of Natural Lighting/Ventilation	Design and Use	S3, S4	Windows are accessible and can ease the use of natural lighting and ventilation	R2	
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)	Design and Use	S4, S5	Integrated wall partitions that bring together different systems (e.g. acoustical insulations and electric connections)	R1	
	22. Utilization of Water Recovery System	Design and Use	S4	Using system that collects and treats the used water to be used for other purposes	R2 and R3	

Legend

R0- R2 = Smarter product use and manufacture

FIG. 5.8 A worksheet for exploring, determining, assessing, and reporting the promotion of CBA in building reuse
Note: Yellow fields must be filled out by the user, if applicable

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	Determinants of Circular Building Adaptability														
	Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
		✕		✕								▨			
		✕	✕	✕	✕			✕				▨			
						✕						▨	▨		▨
										✕				▨	▨
										✕				▨	▨
			✕	✕			✕					▨			▨
										✕		▨		▨	▨

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

Strategies for Circular Building Adaptability in Adaptive Reuse		Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	
Operational Strategies	23. Provision of Shareable Facilities	Design and Use	S4, S6	Shareable office machines	R1	
	24. Application of (or update of) Material Passports	Design, Use Construction	S3, S4, S5, S6	Recording the performance and properties of all used products	R0	
	25. Procurement of the Service of Building Products	Design and Use	S3, S4, S5, S6	Leasing elevators, lightings, façade, or fit outs as a service	R1	
	26. Selective Dismantling	Design, Use Construction	S3, S4, S5, S6	Removing old walls, part by part, to avoid inflicting damage	R3 and **R6**	
	27. Send Back Discarded Material for Reuse/Recycling	Design, Use Construction	S3, S4, S5, S6	Send back decorticated ceiling tiles for recycling or reuse	R3, R7 and **R8**	
	28. Repurpose Old Building Materials/Products	Design and Construction	S4, S5. S6	Repurposing old timber in other forms of finishes	R7	
	29. Product Exchange	Design	S4, S5. S6	Exchanging old products with providers of second hand products	R2 and **R3**	
	30. Implementation of Proactive/ Predictive Maintenance	Use	S3, S4, S5	Implementation of a proactive maintenance of the MEP systems	**R4**	
	31. Repair of Old Building Components/Systems	Design and Construction	S3, S4, S5	Repairing old storing cabinets	**R4 and R5**	
	32. Preservation of Monumental/Old Parts	Design and Construction	S3, S4, S5,S6	Preservation of monumental finishes, doors and windows	**R4 and R5**	
	33. Utilization of Rented-Second-Hand Products	Design and Use	S5, S6	Leasing second hand office fit outs	**R3**	

Legend

R0- R2 = Smarter product use and manufacture

FIG. 5.8 A worksheet for exploring, determining, assessing, and reporting the promotion of CBA in building reuse
Note: Yellow fields must be filled out by the user, if applicable

	Determinants of Circular Building Adaptability														
	Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
						✕						▨		▨	
					✕			✕	✕						
			✕			✕		✕	✕						
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								✕	✕						
				✕				✕				▨	▨		

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

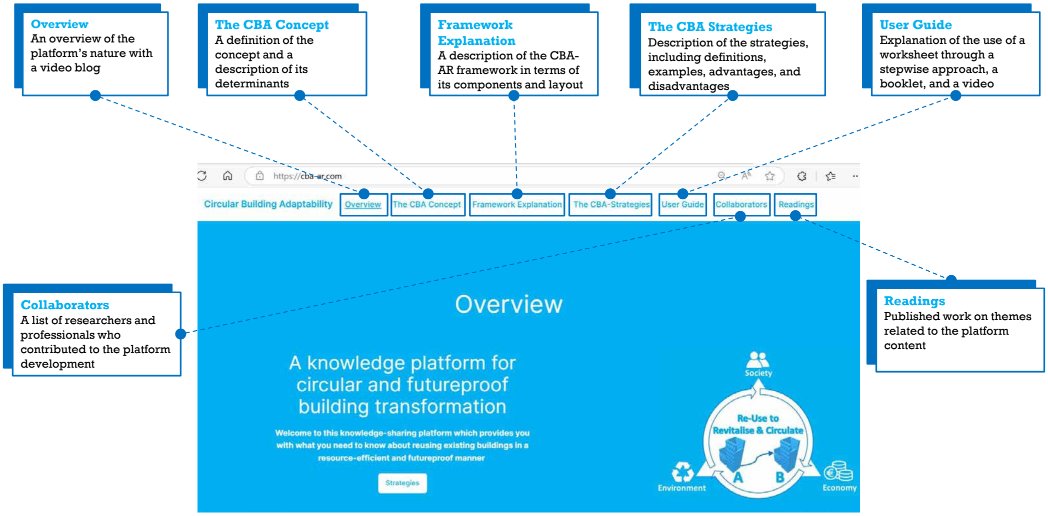
The developed worksheet (Figure 5.8) in this study has a threefold use: identification of the applicable CBA strategies and their solutions in the building layers, assessment of the CBA determinants, and reporting of the CBA performance. This worksheet has been refined after the second and third rounds of iteration. Based on the researcher's experience in the case project, the tool would be used iteratively during different phases of the building design and development. Moreover, to arrive at an informative decision about the applicability of various CBA strategies, using the worksheet requires an interdisciplinary collaboration among different professionals – designers, developers, and other technical specialists – in addition to obtaining the original design documents and accurate inventory of the building assets. This corroborates the discussion by Campbell *et al.* (2024) concerning the importance of collaboration during the development of circular design.

As shown in Figure 5.8, using the worksheet requires the users to acquaint themselves with the framework design and content (Figure 5.5 and Figure 5.6) and the in-depth description of the strategies (Appendix G) which are the first two sections of the booklet. To ease the use of the framework, a hypothetical example has been added to the booklet (Appendix H) as well along with an explanatory video recorded by the researcher. The worksheet utilization as a determining, assessment, and reporting instrument simply requires the user to fill out the last five columns on the right.

To validate its use in the case project, the researcher has used it with the developing manager (Appendix I). The findings of using the worksheet for the case project show that the 10 determinists of CBA have been promoted through four layers of the shearing layer model by Brand (1994). Reflecting on the R-ladder model (Potting *et al.*, 2017), 14 out of the 24 CBA strategies are exclusively related to the so-called smarter product use and manufacture, which indicates that an appropriate level of circularity has been achieved (see Appendix I).

A user-friendly digital platform

Before the third and final reflection workshop, a knowledge-sharing online platform was developed to coherently bring the framework and the associated guiding and usable tools together in an accessible and user-friendly manner. Digital platforms have been considered useful for fostering learning and disseminating knowledge about sustainable building practices, owing to their potential accessibility by a wide range of users (Dipasquale *et al.*, 2024; Kovacic *et al.*, 2020). The developed platform brings together seven pages (Figure 5.9), namely: "Overview", "The CBA Concept", "Framework Explanation", "The CBA-Strategies", "User Guide", "Collaborators", and "Readings", respectively. In the third workshop, the participants were asked to use the platform and reflect on its user-friendliness. Content-wise, the platform has been deemed coherent and comprehensive; however, specific design and minor textual improvements were proposed. Therefore, the research team incorporated those recommendations in finalizing and launching the platform to the public.



Overview
An overview of the platform's nature with a video blog

The CBA Concept
A definition of the concept and a description of its determinants

Framework Explanation
A description of the CBA-AR framework in terms of its components and layout

The CBA Strategies
Description of the strategies, including definitions, examples, advantages, and disadvantages

User Guide
Explanation of the use of a worksheet through a stepwise approach, a booklet, and a video

Collaborators
A list of researchers and professionals who contributed to the platform development

Readings
Published work on themes related to the platform content

Welcome to this knowledge-sharing platform which provides you with what you need to know about reusing existing buildings in a resource-efficient and futureproof manner

FIG. 5.9 The 7-page structure of the established platform

Following is a brief description of the content of these 7 pages (Figure 5.9):

- **Overview:** An overview of the platform, CBA concept, and framework, supported by a video blog.
- **The CBA concept:** A definition of the underlying concept (CBA) and a brief description of its determinants.
- **Framework explanation:** A description of the CBA-AR framework in terms of its components and layout. From this page, users can download the framework.
- **The CBA strategies page:** An in-depth description of the strategies, including definitions, examples, advantages, and disadvantages. On this page, users can browse through the strategies in a dynamic manner.

- **User guide:** An explanation of using the adapted worksheet from the framework as a guiding, assessment, and reporting tool, supported by a stepwise approach explained in an explanatory video along with a hypothetical example and a booklet. From this page, users can download the worksheet, the hypothetical example, and the compiled booklet.

- **Collaborators:** A list of all researchers and professionals who contributed to the development of the platform or the framework.

- **Readings:** Published works on the themes related to the platform focus.

5.7 Discussion

This study aimed to engage with practitioners to test and provide insights into the usability and effectiveness of using the CBA-AR framework as a guiding boundary object for circular adaptive reuse; thereby contributing to bridging the gap between theory and practice. A mixed action research- and design research-oriented approach was adopted using archival research, field observations and interventions, and reflection workshops as methods in an iterative manner

5.7.1 Discussion of the main findings

The findings indicate that the descriptive version of the CBA-AR framework by Hamida *et al.* (2024) (Figure 5.2) has been perceived as an inspiring tool that can be used as a checklist for a spontaneous screening of possible solutions. Although many CBA strategies have been expanded or newly added to the definitive design of the case project by dint of the followed actionable approach in this study, the results show that using the CBA-AR framework as a guiding tool has been difficult because the descriptive version of the CBA-AR framework lacks simplicity in terms of design elaboration, clarity in terms of an adequate description of the strategies, user guide as instructions for professionals, and an indicative means to assess the outcomes of implementing certain CBA strategies. These observations agree Heldal *et al.* (2016) and Gogolla and Selic (2020) indicating that, in practice, descriptive models can be used for documenting or predicting purposes, and prescriptive models are oriented toward development or implementation, whereas both types of models can be flexibly connected.

In this regard, based on the aforementioned observations, the research team iteratively reacted to these practical shortcomings by adding further components to the framework and developing new tools as prototypes. First, content-wise, the description of the CBA-AR framework has been simplified textually and visually. Based on suggestions from the developing team, the 33 CBA strategies have been supplemented with a description, practical examples, and information about their advantages and disadvantages. Second, a user booklet – including a worksheet and a stepwise approach alongside a hypothetical example – was compiled to provide practitioners from the building and real estate market with a practical guide to using the framework as a tool in practice. Third, to improve the usability of the framework and its accessibility by a wider range of professionals, an online platform was established to coherently and comprehensively bring together these components alongside explanatory videos in an accessible and dynamic manner. The platform and its content and design have been considered user-friendly and useful for sharing knowledge about the framework and providing users with clear guidance. Collaboratively using these outcomes has been deemed a prerequisite for their effectiveness in practice, along with obtaining accurate design documents and asset inventory. This corroborates the conclusion of an action-based study by Aigwi *et al.* (2021) which necessitates adopting a collaborative process in adaptive reuse projects to optimize the decision-making process.

5.7.2 Reflection on the practical implications of the outcomes

By virtue of using a mixed design-originated and actionable approach, the research team has been able to bridge the gap between the relevant theory and practice to CBA while bringing about a change in a case project as an experimentation and demonstration in the real world. More specifically, the adopted approach has been pragmatically flexible and enabled us to spontaneously collaborate with practitioners by developing new prototypes based on an iterative and reflexive way of reflecting on observations and interventions in the real world.

These outcomes are manifested in the simplified description of the CBA-AR framework, newly added components to the framework and its strategies, a compiled booklet, and an established online platform. These outcomes turned the CBA-AR framework into a perspective synthesis; thereby, paving the way for transformative change in promoting circularity and adaptability in building reuse projects, not merely by showcasing the collaboration between scholars and practitioners, but also by providing an accessible means for knowledge-sharing. Moreover, the platform and the worksheet can also be used for educational purposes.

Finally, adopting action research in this practice-oriented study enabled us to observe and touch upon other considerations that were not planned to be revealed, similar to what Alves *et al*. (2021) observed and pointed out in their action research study. In our final observations, this has been manifested in the prerequisites we pointed out as requirements for using the framework and its worksheet in practice. Action researchers can learn from our study about how to use mixed action design research in developing and improving frameworks, instruments, or boundary objects tailored for practice and in line with theory.

5.7.3 Indication of the study limitations and possibilities for future research

This study has two limitations. First, context-wise, this study does not explicitly address the role of regulatory actors and legislation in both the process of using the CBA-AR framework and its tools. Second, although the CBA-AR framework has been improved, its improvements are based on lessons extracted from a single case where the findings of a single case research have limited generalizability according to Yin (2009). These two limitations have been beyond the scope of this study. Therefore, future research can focus on exploring how to align the outcomes of this study with existing regulatory policies, as well as testing it in multiple cases and different contexts. This can be carried out using a transdisciplinary approach, as transdisciplinary research in the built environment can bring together participating partners to contribute to sustainable problem-solving and innovation (Femenías and Thuvander, 2018).

5.8 Conclusion and recommendations

Reusing vacant or obsolete buildings is an inevitable type of building alteration, whereas its implementation in a circular and adaptable manner contributes to a resource-efficient and future-proof redevelopment of the built environment. Several frameworks have been developed to provide building stakeholders with the knowledge they need for circular adaptive reuse. However, promoting circularity in this type of project is still an emerging and immature practice.

The presented study in this chapter focused on theory-practice divide by testing and contributing to the useability and effectiveness of the CBA-AR framework as a guiding tool in practice. The CBA-AR framework is the tool we experimented with in this chapter. An action research- and design research-oriented approach was followed in this study to test the usability of the CBA-AR framework during the definitive design phases of a vacant historic office building in the Netherlands. Three rounds of reflection were incorporated, between April 2024 and September 2024. Archival research, field observations and interventions, and reflection workshops were iteratively used as research methods.

The followed design-orientated and actionable approach in this study contributed to getting a better grasp on the useability and effectiveness of the CBA-AR framework in practice based on an iterative process of observing and intervening; thereby reacting to and reflecting on the outcomes from the case project. The results show that the knowledge-based and descriptive version of the CBA-AR framework by Hamida *et al.* (2024) has been usable as an inspiring tool for a quick scan of possible solutions, limiting its effectiveness in improving the outcomes for CBA design. In this context, simplifying the framework description, elaborating on the practicalities of the strategies, incorporating indicative measures, and explaining the use have been perceived as essential prerequisites for improving the usability and effectiveness of the CBA-AR framework.

To satisfy these 4 prerequisites, the research team took the following actions: visually and textually simply describing the framework components in a simple manner; adding an in-depth explanation of the CBA strategies; incorporating the R-ladder model of the framework along with the adaptation of a worksheet; and compiling a user booklet with a stepwise approach as well as establishing a user-friendly online platform, respectively. The outcomes of these actions were refined during the different moments of reflection based on inputs from the developing team of the case project.

By following a pragmatic mixed research approach bringing design and actionable components together, this study directly bridges the distance between what has been conceptualized in the literature of CBA and what occurs in the real world. More specifically, the lessons learned from the case project, as a demonstration case, along with produced outcomes – manifested in the form of a prescriptive prototype, assessment tool, and the integrated, self-explained accessible knowledge-sharing platform pave the way – pave the way for operationalizing CBA in future building reuse projects by means of accessible learning, user guide and usable instruments in design. For the relevant body of knowledge to building adaptation, circularity, and adaptability, scholars can build on the lessons learned to further develop integrative decision-making tools that are function- or scenario-specific.

Based on the outcomes of this study, the researcher put forward the following recommendations for practitioners:

- Users of the CBA-AR framework need to compile an inventory of the building assets and documents before using the CBA-AR framework as a guiding, assessment, and reporting instrument.
- An interdisciplinary approach needs to be used while designing for CBA in building reuse projects to contribute to arriving at informative decisions on the applicable strategies and their practical and effective solutions.

This study did not explicitly consider the role of policies and legislation in the use of the CBA-AR framework. Additionally, the empirical part has been limited to a single case. Thus, future research can focus on aligning the CBA-AR framework with existing regulatory processes and guidelines using a transdisciplinary approach, exploring the use of the framework in other case projects with different contexts. Ultimately, the outcomes of this study can contribute to a transformative change by incorporating circular principles in building reuse projects. For action researchers, this study shows an application of using mixed action design research as a theory-practice approach to improving and enhancing frameworks from the literature and appropriating them for practice

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6 Conclusion

6.1 Overview

Adaptive reuse of buildings, also called building transformation or building conversion, aligns with CE as a practice that reuses the built assets and prolongs their utility, thereby reducing waste generation and the need to consume primary resources.

On the other hand, altering and adaptively reusing buildings can be triggered by various external and internal factors such as functional obsolescence, market dynamics, population growth, technological evolutions, and changes in user preferences. Moreover, previous research has indicated that there is limited consideration of CE in adaptive reuse.

Resource efficiency and future-proofing can be realized by promoting principles of circularity and adaptability. The former concerns waste reduction and resource efficiency, while the latter addresses the capacity to accommodate building changes. Reviewing the literature points out that there is a lack of practical tools that can be used by professionals from the building and real estate sectors to promote both qualities in adaptive reuse projects.

This research aimed to provide building and property practitioners with a guiding instrument to help them gain knowledge about the circular and adaptable building transformation. This research focused on answering the following main research question:

How can building adaptive reuse projects be circular and adaptable?

To answer this main research question, the following four sub-questions were inquired:

1. **What is the conceptual interrelationship between building circularity and adaptability?**
2. **What are the applicable circularity and adaptability strategies in adaptive reuse projects and their enablers and inhibitors?**
3. **What strategies and factors should be considered for circular and adaptable adaptive reuse?**
4. **How can the developed framework for circular and adaptable adaptive reuse projects be usable and effective in practice?**

To answer the sub-questions, a quadrant and stepwise research design of four studies was developed and used (see section 1.4). The first study – *Reconceptualization of relevant concept* – was theoretical and used an integrative literature review as a methodology. The second study – *Exploration of demonstration cases* – was empirical and used case study research as an approach. The third study – *Framework co-development* – was participatory and used a series of co-creation workshops as a methodology. The fourth study – *Framework implementation in design* – was actionable and used action design research as an approach.

6.2 Key research findings

6.2.1 Key findings from study 1: Reconceptualization of relevant concepts

This study contributed to rethinking the interrelationship between building adaptability and building circularity, thereby bringing them together (see Chapter 2). Particularly, it leveraged knowledge and discussion from literature about building adaptability and the emerging models for circular buildings.

The findings of this literature study pointed out that promoting adaptability in buildings lays the ground for promoting circularity, as adaptable design facilitates reversing the building assets in their value chain. The critical analysis led to synthesizing a new reconceptualization that combines both concepts. This concept has been called *circular building adaptability* (CBA) and was defined 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"*. Based on the components of both concepts and their interconnection (Figure 6.1), CBA has been expressed with ten 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".

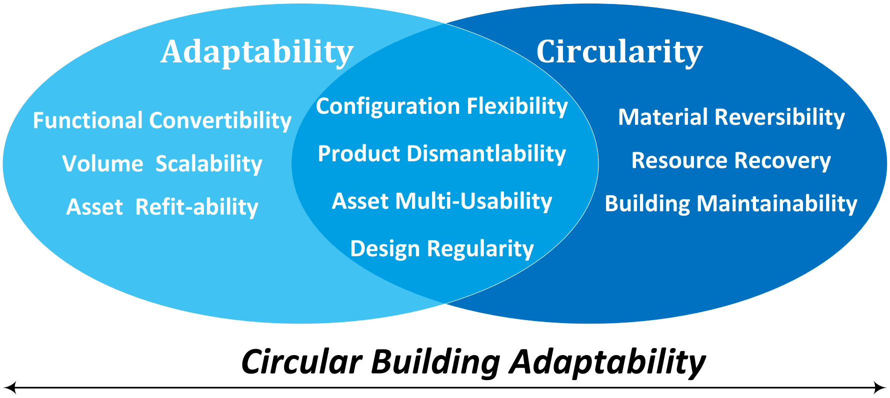


FIG. 6.1 Determinants of circular building adaptability

The study concluded that promoting CBA has the potential to reduce waste generation in new and existing buildings while promoting the capacity to meet user demands, foster property's long-lasting functionality, cope with market dynamics, and add value to building assets.

6.2.2 Key findings from study 2: Exploration of demonstration cases

This study contributed to expanding the conceptualization of CBA from study 1 with empirical observations from five building transformation projects. (see Chapter 3). It drew lessons about CBA strategies applied in adaptive reuse projects, along with factors that could enable or inhibit those strategies.

The study identified a series of passive, active, and operational strategies that can be implemented to promote CBA. In the five case studies, “configuration flexibility”, “product dismantlability” and “material reversibility” have been promoted by using standardized building components, separating walls from the structure, and using demountable building components. Asset multi-usability, design regularity, resource recovery, volume scalability, and asset refit-ability have been promoted across the five cases on various levels. However, building maintainability and functional convertibility were less frequently promoted.

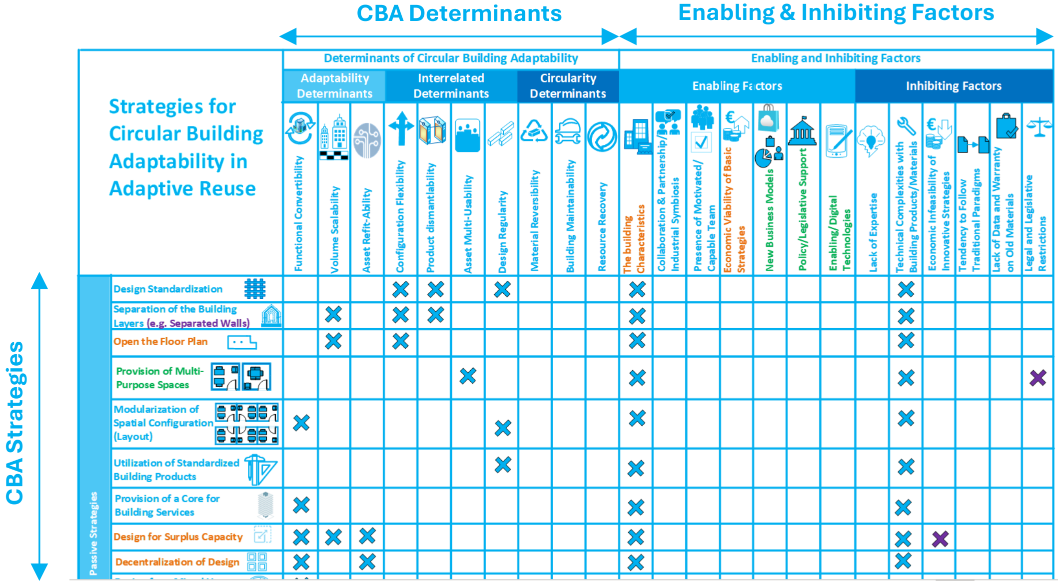
Different enabling and inhibiting factors for implementing the CBA strategies have been revealed. Enabling factors were: low cost of material reuse, collaboration among team members, and organizational motivation. On the other hand, lack of information, technical complexities, lack of circularity expertise, and infeasibility of innovative circular solutions were the main inhibiting factors.

Although the findings of the five case studies cannot be generalized as they are case-specific, they provide valuable insights on how to promote CBA in transformation projects considering the factors that could facilitate or hinder the implementation of the CBA strategies.

6.2.3 Key findings from study 3: Framework co-development

This study was built on studies 1 and 2 to develop a knowledge-based framework for circular and adaptable building transformation (see Chapter 4). Archival research was conducted to synthesize the first version of the framework. Following, it was collaboratively validated and expanded by two co-creation workshops and triangulated with structured interviews, thereby bridging the gap between theory and practice using participatory research.

The developed framework is called a framework for circular building adaptability in adaptive reuse (CBA-AR). It is a descriptive synthesis that brings together the explored variables in study 2, namely the CBA determinants, CBA strategies, and the enabling and enabling factors for the CBA strategies (Figure 6.2). This participatory study refined many strategies and factors and added new ones. In addition, it added a subjective evaluation of the CBA strategies in terms of three aspects: applicability in practice, effectiveness in promoting CBA, and economic feasibility (see sub-subsection 4.6.5).



CBA Determinants

Enabling & Inhibiting Factors

CBA Strategies

		Determinants of Circular Building Adaptability										Enabling and Inhibiting Factors												
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants			Enabling Factors							Inhibiting Factors					
	Strategies for Circular Building Adaptability in Adaptive Reuse	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Viability of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions
Passive Strategies	Design Standardization				✖	✖		✖				✖								✖				
	Separation of the Building Layers (e.g. Separated Walls)		✖		✖	✖						✖								✖				
	Open the Floor Plan		✖		✖							✖								✖				
	Provision of Multi-Purpose Spaces						✖					✖								✖				✖
	Modularization of Spatial Configuration (Layout)	✖						✖				✖								✖				
	Utilization of Standardized Building Products							✖				✖								✖				
	Provision of a Core for Building Services	✖										✖								✖				
	Design for Surplus Capacity	✖	✖	✖								✖								✖	✖			
	Decentralization of Design	✖		✖								✖								✖				

FIG. 6.2 The typical layout of the CBA-AR framework

The finalized version of the CBA-AR framework includes 33 strategies – 15 passive, 7 active, 11 operational, and 7 inhibiting factors. The subjective evaluation results pointed out that alignment of the building design with the real estate strategy, utilization of dismountable building components, utilization of renewable energy technologies, utilization of flexible and integrated installations, application of material passports, and provision of shareable facilities are the most promising ones according to the overall score of each strategy.

6.2.4 Key findings from study 4: Framework implementation in design

This study contributed to testing and improving the usability and effectiveness of the CBA-AR framework developed in study 3 in practice, using a mixed approach of action research and design research (see Chapter 5). Particularly, this study leveraged outcomes from observing, acting, and reflecting in action to examine the usability and effectiveness of the CBA-AR framework. A reuse project of a vacant monumental office building in South Holland was used as a case study, where the researcher tested the CBA-AR framework, using three rounds of observing, intervening, and reflecting in action between May 2024 and September 2024.

The observations from the first round indicated that the developed CBA-AR framework in study 3 has been useful for a quick scan of possible solutions. Still, the results pointed out that the framework lacks a simplified description that could increase its useability. Accordingly, several actions have been untaken during the other two rounds to improve the usability and effectiveness of the framework, namely incorporating exemplary solutions for the CBA strategies into the framework, visually and textually simplifying the description of the framework components in a blocks-oriented scheme (Figure 6.3); compiling a user booklet including in-depth-description of the CBA-strategies, a worksheet, a user guide, and a hypothetical example; and finally building a user-friendly platform bringing together the previously produced outcomes along with an explanatory video (Figure 6.4), respectively.

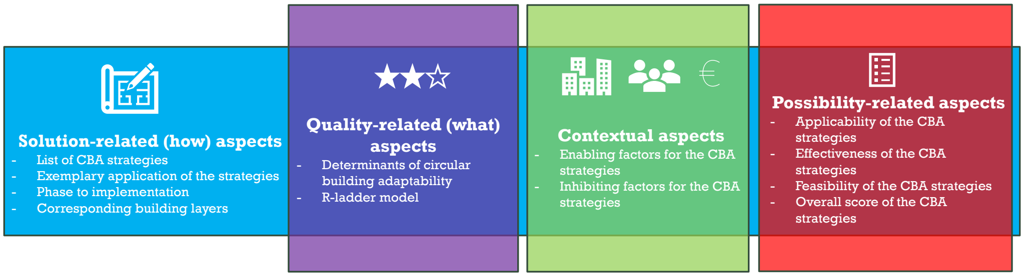
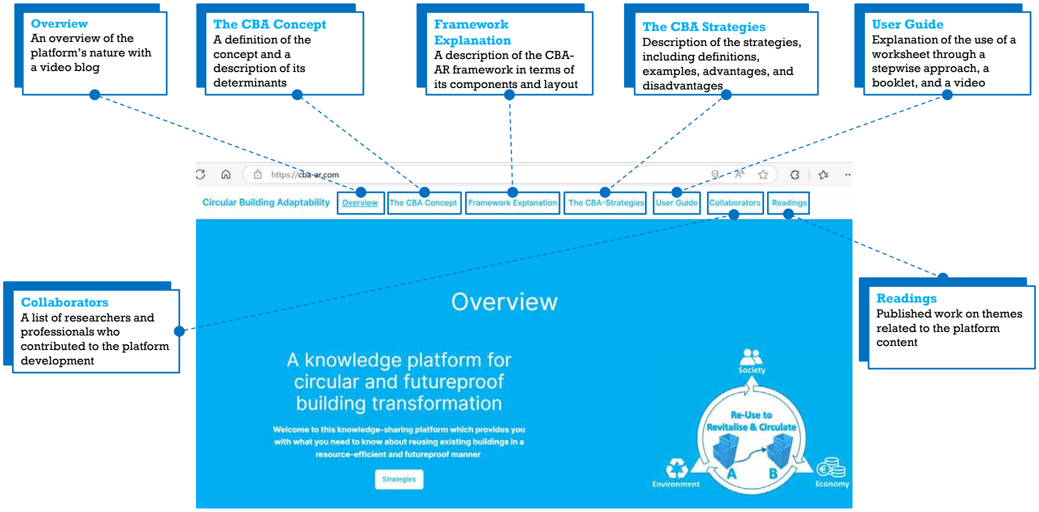


FIG. 6.3 A simplified blocks-originated visualized description of the components of the CBA-AR framework



Overview
An overview of the platform's nature with a video blog

The CBA Concept
A definition of the concept and a description of its determinants

Framework Explanation
A description of the CBA-AR framework in terms of its components and layout

The CBA Strategies
Description of the strategies, including definitions, examples, advantages, and disadvantages

User Guide
Explanation of the use of a worksheet through a stepwise approach, a booklet, and a video

Collaborators
A list of researchers and professionals who contributed to the platform development

Readings
Published work on themes related to the platform content

Overview

A knowledge platform for circular and futureproof building transformation

Welcome to this knowledge-sharing platform which provides you with what you need to know about reusing existing buildings in a resource-efficient and futureproof manner

FIG. 6.4 Layout of the built platform for the CBA-AR framework

The CBA-AR framework from study 3 was turned into a prescriptive, explained, and accessible tool for exploring, assessing, and reporting CBA-AR. This has been fulfilled by leveraging insights from observing, acting, and collaboratively reflecting in action. The study concluded that further research on its alignment with legislative policies and processes is needed. Moreover, the produced outcomes are based on extracted lessons from a single contextual case, which might impose some limitations about the generalizability of the tool's effectiveness in other contexts.

6.3 Answer to the main research question

Figure 6.5 visually illustrates the main conclusion of this research study. Answering the main research question – *How can building adaptive reuse projects be circular and adaptable?* – based on the answers to the four sub-questions answered by the four abovementioned studies, this research study concludes that circularity and adaptability in adaptive reuse (building transformation) projects can be promoted by implementing a series of passive, active, and operational strategies that promote the defined 10 determinants of CBA in this research.

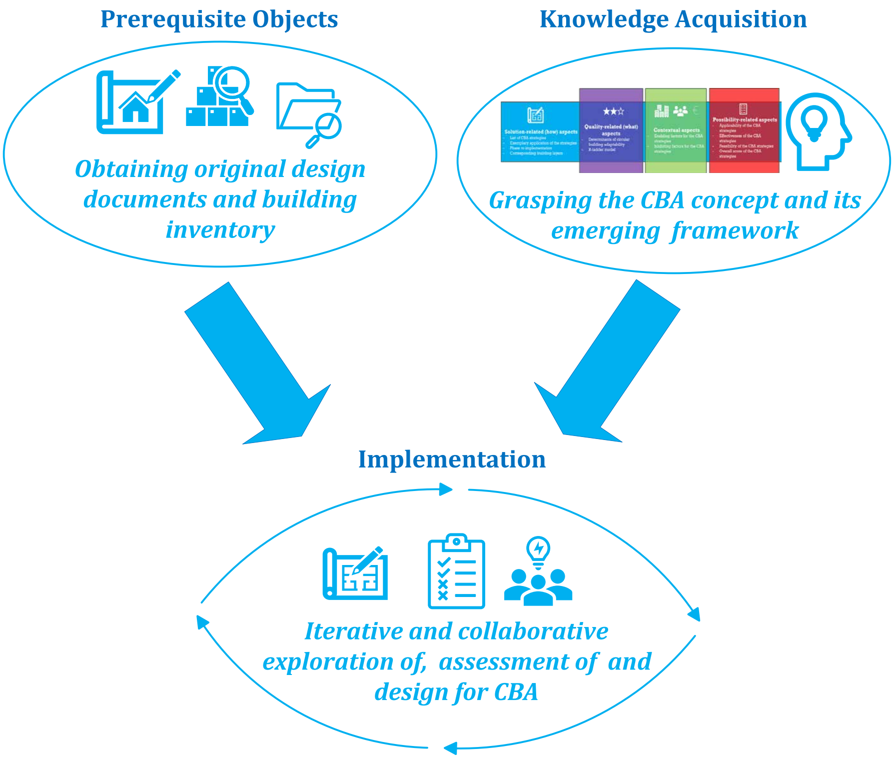


FIG. 6.5 Main research conclusion

To do so in practice, designers and real estate professionals should grasp the CBA determinants and acquaint themselves with the corresponding CBA strategies by using the CBA-AR framework and its worksheet as a guiding, assessment, and reporting instrument on an iterative and interdisciplinary basis. This should collaboratively take place at the outset of a project's definitive design phase. Content-wise, this should take into consideration the technical condition of the building assets as well as the applicable legislative requirements.

Thus, based on the insights gained from the action research study presented in Chapter 5, other specialists need to be involved along with the building designer and real estate professionals – such as the developing managers, project managers, financial analysts, MEP experts, and installation specialists – as key influencers in the design decisions. The prerequisites for effectively using the CBA-AR framework are obtaining original design documents and compiling an inventory of the building assets.

For instance, part of a series of joint meetings between the developer, designer, and installation specialists of an adaptive reuse project can be customized for exploring the CBA-AR framework, the CBA strategies, and their applicability in the project. In these moments, these parties would use and refer to the CBA-AR framework as a boundary object for brainstorming, while the original building documents and asset inventory would act as project-specific data determining the applicability of the possible strategies in light of the physical spatial situation of the project. During the definitive design development, the worksheet can be frequently used as a checklist and assessment tool.

6.4 Recommendations

As this research has provided a new reconceptualization and a new framework including a series of unconventional strategies, the operationalization of the outcomes in the real world would require efforts from actors that play a key role in building transformation projects. These actors would involve design professionals as solution-makers, real estate professionals as owners or financiers, and policymakers as regulators. Therefore, this research has put forward a threefold series of recommendations.

6.4.1 Recommendations for design professionals

Designers should consider incorporating passive and active design strategies into the new design. Based on Chapter 4, the following is a series of key recommendations, as design-oriented guidelines, for design professionals when designing for CBA-AR:

- Promote configuration flexibility, product demountability, and volume scalability by using demountable building products and separating the building layers.
- Promote design regularity by modularizing the spatial configuration, standardizing the design of the building components and products (e.g. standardized panels and doors), and utilizing flexible and integrated installation.
- Promote functional convertibility and asset refit-ability by designing for surplus capacity (e.g. using extra acoustical wall insulations) and compartmentalization of design.

- Promote resource recovery by using renewable energy technologies, facilitating the use of natural lighting and ventilation, and using bio-based products and materials.
- Use secondary and reusable materials and repurpose old materials when possible to promote material reversibility.
- Provide sharable and multipurpose spaces as well as sharable facilities to foster asset-multi-usability in the building design.

These recommendations are proposed in line with the 10 determinants of CBA and put forward for architects and design professionals specifically for enhancing the design for CBA in adaptive reuse projects.

6.4.2 Recommendations for real estate professionals

As real estate professionals represent developers and investors who play the role of owner or financier, they need to consider bringing the CBA-AR framework into action in their transformation projects. Based on the observations from Chapter 5, this can be fulfilled by considering the following recommendations:

- Provide design professionals with a compiled and detailed inventory of the building assets at the beginning of the early design phases, including their visuals, quantity, and condition assessment. Otherwise, compile or update building records of the building design and asset inventory of these data are unavailable or inaccurate.
- Implement operational CBA strategies during the project lifespan by applying material passports, implementing proactive/predictive maintenance, sending back discarded materials for reuse, and preserving monumental/old parts.
- Consider investing in innovative and future-oriented circularity and adaptability, procuring the service of changeable building assets or systems (e.g. elevators, fit-outs, or lighting as a service) instead of ownership.

6.4.3 Recommendations for policymakers

Existing legislation for building transformation does not necessarily encourage developers and designers to promote either CBA, as a newly emerging concept, or circularity or adaptability in adaptive reuse. As policymakers are players in formulating and implementing policies, they have a vital role in facilitating the implementation of the CBA-AR framework in practice through legislative procedures. Accordingly, the following recommendations have been put forward for policymakers:

- Amend building transformation legislation and regulations to incorporate the key effective CBA strategies as requirements, such as sending back discarded material for reuse, using demountable building components and products, and separating the building layers.
- Provide applicants for building transformation permits with advice about using the CBA-AR framework as a guiding tool for a resource-efficient and future-proof redevelopment of the built environment.
- Mapping and bringing together private and public organizations concerned with the CBA strategies to foster collaboration in industrial symbiosis, including suppliers, design firms, reuse agencies, developers, and contractors.

6.5 Research contributions and implications

6.5.1 Contributions to the body of knowledge and education

This study scientifically has broadened the body of knowledge in the discipline of CBE by providing a new reconceptualization, namely the CBA. It brings together the concepts of building circularity and adaptability, contributing to CE and aligning with its models while not overlooking the functionality and future-proofing of the built environment (see Chapter 2). The CBA concept has been used in this research to guide discussion about circular and adaptable solutions for existing and new buildings (see sub-subsection 4.5.1). In particular, the CBA concept, along with the explored and mapped strategies and their enabling and inhibiting factors – as practical solutions connected to contextual influences, together provide a knowledge base capturing how circularity can be promoted in adaptive reuse practices while keeping the built assets functional and futureproof for society.

For design education, the CBA-AR framework can be used to teach design students how to come up with resource-efficient and future-proof designs for refurbishing or transforming existing buildings based on the 33 CBA strategies. For real estate education, the CBA-AR framework and its strategies can be incorporated into themes related to sustainable real estate and decision-making on circular investments.

6.5.2 Practical and societal implications

This study carries societal and practical implications for the short and long term. It could potentially reshape adaptive reuse practices by providing practitioners with a knowledge-based framework for circular and adaptable building transformation (see Chapter 4). The framework can be used systematically and iteratively as a guiding, assessment, and reporting instrument by design real estate practitioners worldwide (see Chapter 5). The outcomes can pave the way for bringing about a change in building transformation projects in the long run.

6.6 Research limitations

The limitations of this study are twofold: content-related and implication-related.

First, in terms of content, the CBA-AR framework developed in this study has certain limitations, particularly regarding its coverage of all process actors and building functions, as well as the method used in its construction and validation. The study does not explicitly consider the vital role of legislative actors and policies in the development and application of the framework. In fact, legislation and regulation have a direct bearing on building reuse practices through their imposed requirements for heritage preservation and the acquisition of transformation permits, so researching their vital role is significan. Additionally, while the framework is designed for general building transformation projects, it does not incorporate building typology-specific aspects. Regarding the methodology used to construct and validate the CBA-AR framework, the study does not explore the impact of implementing CBA strategies during the project use phase, including their environmental and social effects. Furthermore, the framework has only been tested in a single case study, which may limit the generalizability of the insights obtained (See Chapter 5).

Second, in terms of implications, the developed CBA-AR framework in this study, as any type of proposed or designed framework and tool for practice, certainly does not ensure a shift in current practices or practitioners' behavior on a broader societal scale toward adopting new concepts in the real world. This is because frameworks, even if they are prescriptive, are constructed networks bringing together interconnected or relevant concepts, processes, and rules, serving as informing or guiding systems that can be optionally used by professionals and organizations rather than obligatorily.

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6.7 Directions for future research

Reflecting on the aforementioned limitations, future research can address them by focusing on the following:

- Exploring ways to align the CBA-AR framework with existing building transformation legislation and regulations. As legislation, regulations, zoning policies, and municipalities play a vital role in regulating existing building transformation practices, their role should be promoted and researched. This can be carried out by transdisciplinary and longitudinal research which brings together policy-oriented, transitional, behavioral, urban, and design studies while leveraging methods used in co-creation and living lab research.

- Expanding the CBA-AR framework further and connecting it with specific building typologies and adaptive reuse scenarios. Although adaptive reuse projects are implemented in various conversion scenarios and building typologies, it is still important to provide practitioners with function- or scenarios-specific tools. This can be realized by either participatory research or action design research where experts are involved together to customize or adapt case- and scenario-specific tools for the CBA-AR framework.

- Analyzing the environmental, economic, and social impact of the CBA strategies during the project phase. This can be carried out by conducting lifecycle costing (LCC) and life cycle assessment (LCA) on different solutions incorporated into the CBA strategies in the CBA-AR framework. The outcomes of this kind of study will provide building and real estate stakeholders with measurements of the impact of the specific solutions they chose for the CBA strategies.

As indicated in **sub-subsection 5.7.3**, a transdisciplinary research approach can be adopted. It could bring together participating partners to contribute to sustainable problem-solving and innovation. Furthermore, conducting a longitudinal study on redesigned transformation projects using the CBA-AR framework would be useful to observe the outcomes and other impacts during the other phases of the project lifecycle.

Ultimately, the outcome of this research can pave the way for enhancing the practice of building transformation by providing knowledge about “what to consider” and “how to do” within the context of circular and adaptable building transformation.

Appendices

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APPENDIX A

Interview Guide for Exploring the Operationalization of Circular Building Adaptability in Adaptive Reuse

1 Introduction

I am Mohammad B. Hamida, a PhD researcher at the Department of Management in the Built Environment, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands.

I am conducting this interview as a part of an ongoing PhD project, working title *"Circular Building Adaptability and Adaptation Framework: Conception, Exploration and Operationalization"*, that focuses on conceptualizing, exploring and operationalizing a framework for circular building adaptability (CBA). The framework will depict proactive and reactive strategies for previously defined CBA determinants based on a theoretical study (literature review). This interview is part of the first field study. The focus of this interview is twofold:

- Validating theoretical outcomes of defining a conceptual framework for circular building adaptability and circular (CBA).
- Exploring the operationalization of CBA in circularity-oriented building projects, including other context-related issues: enablers and barriers.

You are being interviewed to contribute to this study due to your previous experience with building projects that operationalized circularity and adaptability. This interview will take an hour or so. In this interview, you will be asked to answer series of questions regarding your perceptions and previous experience on the mentioned two themes. The interview will be recorded and then transcribed.

The mitigation of all potential risks – such as online breaches and identification of personal data – is being seriously considered in this research. Accordingly, the collected data will be processed according to the developed data management plan by the researcher. This will be carried out in line with the data protection policies at TU Delft, so which will ensure the security of your data and prevent all potential online breaches as much as possible. To protect any personal or private data – such as name, professional, and project title – from any kind of online breaches or hacks, the recordings will be immediately stored in the project storage drive provided by TU Delft after the interview. The recordings will be accessed only by the research team.

To keep the privacy of the personal data and prevent their identifiability by others, the recordings will be transcribed and processed to be in a form of anonymized transcripts. The anonymized outcomes will be used in the research write-up and scientific publications. At the end of this interview, I will ask you to voluntarily contribute to the sample of this research by providing name of other participants or case projects, where feel free not to answer that if you think that could be harmful to share others' information. You can ask any question; also withdraw from the interview at any time you wish. Finally, this interview will be conducted in line with the applied health measures in the Netherlands for the privation of the spread of COVID-19. Thus, I would like to ask for your consent for:

- Conducting this interview in line with the current COVID-19 measures applied in the Netherlands.
- Recording the audio of this interview.
- Allowing the research team only to have an access to the recordings and your background information (name, affiliation, professional field, project name).
- Transcribing the recordings into anonymized transcripts
- Allowing the research team to analyse and use the transcripts in the research write up and publications.

2 Background

- Name:
- Interviewee No.
- Affiliation and address:
- Professional field (role):
- Years of experience:
- Name of project:

3 Opening Questions (broad questions aimed at building rapport with the interviewee)

1. What are the influences (or impact) of circularity initiatives on your practices?
2. What do you think about the circularity in building adoption in the property market and building industry?

4 Key Questions (core questions to validate, explore and understand)

4.1 Validation of theoretical outcomes

I would like now to discuss with you how do you conceive the ways of implementing strategies that contribute to the achievement of circularity and adaptability in buildings.

1. According to your practical experience, how do you think the synergy (integration) between building adaptability (transformability and flexibility) and circularity looks like in the development of a new or existing building? *I mean what are the things that make the building adaptable for change and circular at the same time*?
2. What are the strategies – actions or solutions – that could be considered as a means that could facilitate this synergy/integration?
3. What are the things that could enable adopting such strategies in the property market when it comes to adapting vacant and outdated premises? (e.g. things that facilitate/ pave the way for this)
4. What are the things that could obstruct – impede (e.g. obstacles/bottlenecks) the adoption of such strategies in the property market when it comes to adapting vacant and outdated premises?

4.2 Exploration of the Operationalization of CBA in circularity-oriented adaptations

Let’s dive in the real experience, I would like now to discuss with you your experience with the project (project title:--------------------) that you have been involved in, and talk directly about practical things.

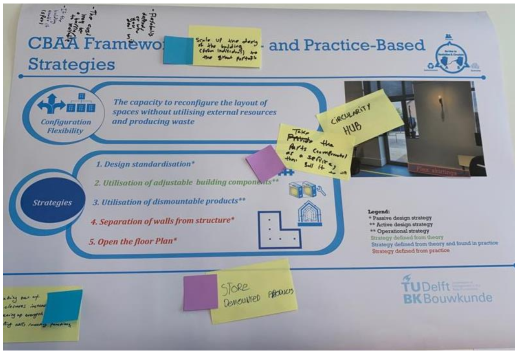
1 In the project that you have been involved in, why this project was adapted?
2 For instance, maybe was the building outdated or vacant?
3 Why circularity was considered in the project?
4 What were the circular strategies – actions and solutions – that were carried out in the project?
5 Were there other strategies that you have considered and not implemented? And why?
6 What were the aspects that obstructed the implementation of these strategies?
7 What were the aspects that facilitated (paved the way) the implementation of such strategies?

5 Closing Questions (questions to slowly reduce the apport, create a distance again and leave the interviewee)

1 According to the valuable experience and information you have shared with me, how do you see the future of circularity and adaptability in your occupation (profession/industry)?
2 Is there any further information that you would like to add?
3 If you don’t mind, would you recommend other participants to interview or cases to consider in this research project? *Feel free if you do not want to answer this question or if you think that is going to be harmful for others*

APPENDIX B

Outcomes of validating and collaboratively expanding the CBA strategies


CBAA Framework – Theory- and Practice-Based Strategies

Configuration Flexibility

The capacity to reconfigure the layout of spaces without utilising external resources and producing waste

Strategies

1. Design standardisation*
2. Utilisation of adjustable building components**
3. Utilisation of dismountable products**
4. Separation of walls from structure*
5. Open the floor Plan*

Legend:
* Passive design strategy
** Active design strategy
** Operational strategy
Strategy defined from theory
Strategy defined from theory and found in practice
Strategy defined from practice

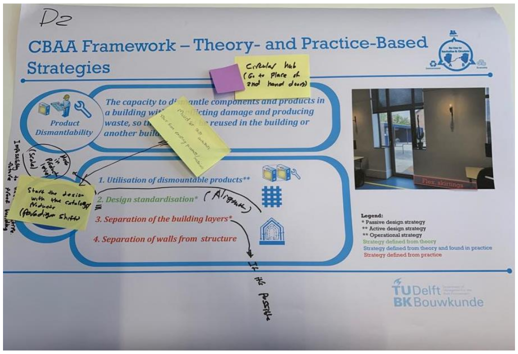
Scale up the degree of the building (from individual) to the grand portfolio

CIRCULARITY HUB

Take ~~Provide~~ the parts (components) as a service, then sell it

STORE DEMOUNTED PRODUCTS

Configuration Flexibility


D2

CBAA Framework – Theory- and Practice-Based Strategies

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

Strategies

1. Utilisation of dismountable products**
2. Design standardisation* (Alignment)
3. Separation of the building layers*
4. Separation of walls from structure

Legend:
* Passive design strategy
** Active design strategy
** Operational strategy
Strategy defined from theory
Strategy defined from theory and found in practice
Strategy defined from practice

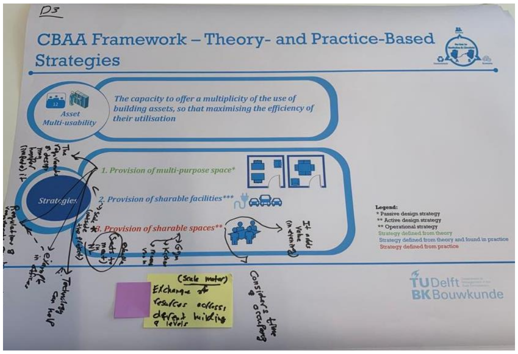
Circular hub (Go to place of 2nd hand doors)

Start the design with the catalogue products (Paradigm shift)

(Scale)

It is possible

Product Dismantlability


D3

CBAA Framework – Theory- and Practice-Based Strategies

Asset Multi-usability

The capacity to offer a multiplicity of the use of building assets, so that maximising the efficiency of their utilisation

Strategies

1. Provision of multi-purpose space*
2. Provision of sharable facilities***
3. Provision of sharable spaces**

Legend:
* Passive design strategy
** Active design strategy
** Operational strategy
Strategy defined from theory
Strategy defined from theory and found in practice
Strategy defined from practice

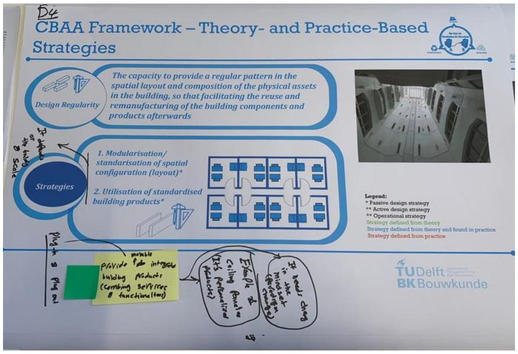
(Scale matter) Exchange of resources across different building & levels

It adds value (in evening)

Considers time & occupancy

Technology can help

Asset Multi-Usability


D4

CBAA Framework – Theory- and Practice-Based Strategies

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

Strategies

1. Modularisation/ standarisation of spatial configuration (layout)*
2. Utilisation of standardised building products*

Legend:
* Passive design strategy
** Active design strategy
** Operational strategy
Strategy defined from theory
Strategy defined from theory and found in practice
Strategy defined from practice

It depends on the building & scale

Plug-in & Plug out

Provide movable integrated building products (combining services & functionalities)

Example of ceiling panels (It's personalized products)

It needs change in the mindset (Paradigm change)

Design Regularity

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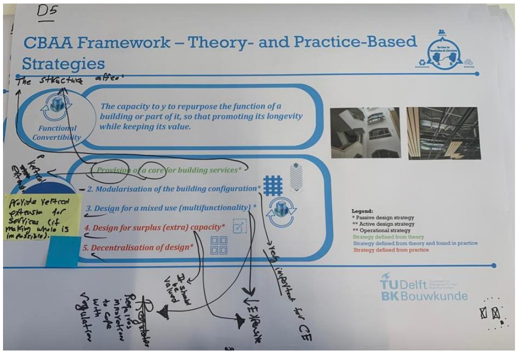

D5

CBAA Framework – Theory- and Practice-Based Strategies

Functional Convertibility

The capacity to y to repurpose the function of a building or part of it, so that promoting its longevity while keeping its value.

1. Provision of a core for building services*
2. Modularisation of the building configuration*
3. Design for a mixed use (multifunctionality) *
4. Design for surplus (extra) capacity*
5. Decentralisation of design*

Legend:
- * Passive design strategy
- ** Active design strategy
- *** Operational strategy
- Strategy defined from theory
- Strategy defined from theory and found in practice
- Strategy defined from practice

Provide vertical extension for services (it making whole is in possible).

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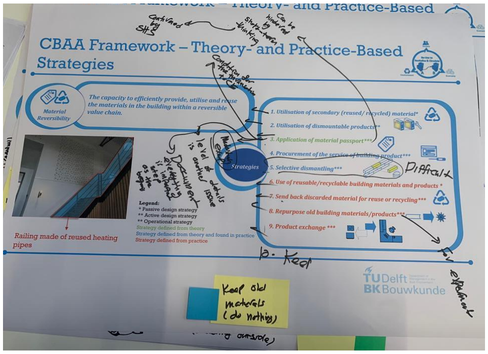
Functional Convertibility



CBAA Framework – Theory- and Practice-Based Strategies

Material Reversibility

The capacity to efficiently provide, utilise and reuse the materials in the building within a reversible value chain.

Strategies

1. Utilisation of secondary (reused/recycled) material*
2. Utilisation of dismountable products**
3. Application of material passport***
4. Procurement of the service of building product***
5. Selective dismantling***
6. Use of reusable/recyclable building materials and products *
7. Send back discarded material for reuse or recycling***
8. Repurpose old building materials/products**
9. Product exchange ***

Railing made of reused heating pipes

Legend:
- * Passive design strategy
- ** Active design strategy
- *** Operational strategy
- Strategy defined from theory
- Strategy defined from theory and found in practice
- Strategy defined from practice

Difficult

Keep old materials (do nothing)

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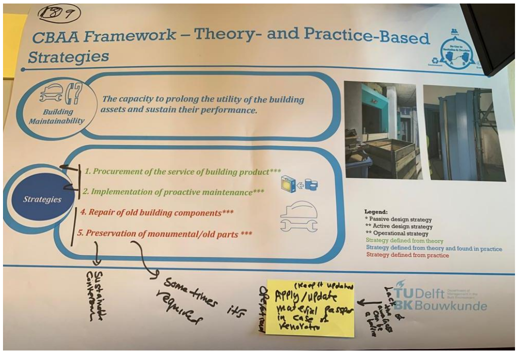
Material Reversibility



CBAA Framework – Theory- and Practice-Based Strategies

Building Maintainability

The capacity to prolong the utility of the building assets and sustain their performance.

Strategies

1. Procurement of the service of building product***
2. Implementation of proactive maintenance***
4. Repair of old building components***
5. Preservation of monumental/old parts ***

Legend:
- * Passive design strategy
- ** Active design strategy
- *** Operational strategy
- Strategy defined from theory
- Strategy defined from theory and found in practice
- Strategy defined from practice

Sometimes required

(Keep it updated) Apply/update material passport in case of renovation

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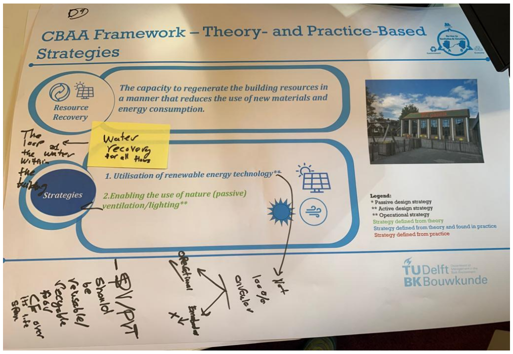
Building Maintainability



D9

CBAA Framework – Theory- and Practice-Based Strategies

Resource Recovery

The capacity to regenerate the building resources in a manner that reduces the use of new materials and energy consumption.

Strategies

1. Utilisation of renewable energy technology**
2. Enabling the use of nature (passive) ventilation/lighting**

Water recovery for all things

Legend:
- * Passive design strategy
- ** Active design strategy
- *** Operational strategy
- Strategy defined from theory
- Strategy defined from theory and found in practice
- Strategy defined from practice

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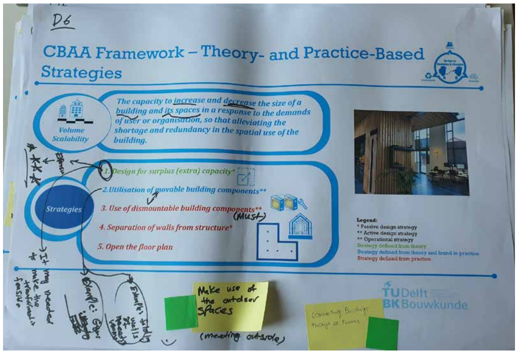
Resource Recovery



D6

CBAA Framework – Theory- and Practice-Based Strategies

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.

Strategies

1. Design for surplus (extra) capacity*
2. Utilisation of movable building components**
3. Use of dismountable building components** (Must)
4. Separation of walls from structure*
5. Open the floor plan

Legend:
- * Passive design strategy
- ** Active design strategy
- *** Operational strategy
- Strategy defined from theory
- Strategy defined from theory and found in practice
- Strategy defined from practice

Make use of the outdoor spaces (meeting outside)

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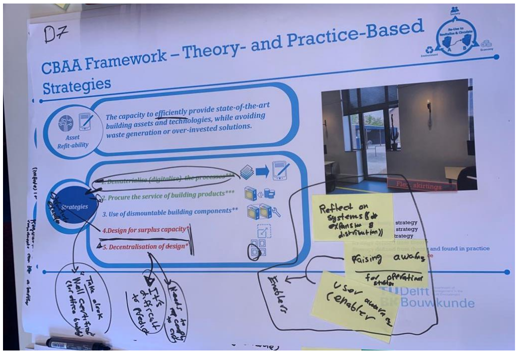
Volume Scalability



D7

CBAA Framework – Theory- and Practice-Based Strategies

Asset Refit-ability

The capacity to efficiently provide state-of-the-art building assets and technologies, while avoiding waste generation or over-invested solutions.

Strategies

1. Dematerialise (digitalise) the processes
2. Procure the service of building products***
3. Use of dismountable building components**
4. Design for surplus capacity*
5. Decentralisation of design*

Reflect on systems (& extension & distribution)

Raising awareness for operational side

User (enabler)

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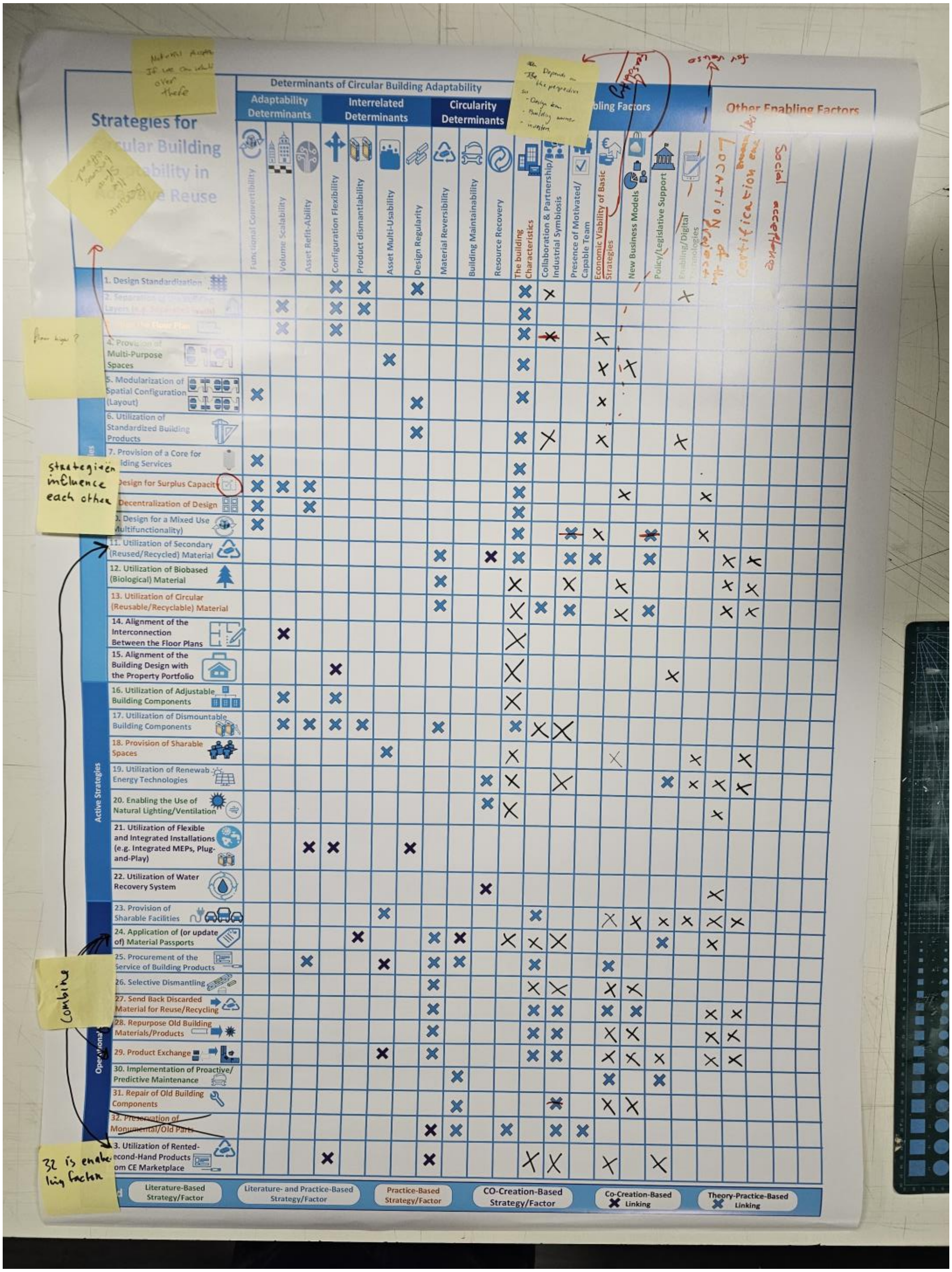
Asset Refit-Ability

APPENDIX C

Outcomes of validating and collaboratively expanding the enabling factors



Strategies for Circular Building Adaptability in Adaptive Reuse

Determinants of Circular Building Adaptability

Adaptability Determinants

Interrelated Determinants

Circularity Determinants

Enabling Factors

Other Enabling Factors

Functional Convertibility

Volume Scalability

Asset Refit-Ability

Configuration Flexibility

Product dismantlability

Asset Multi-Usability

Design Regularity

Material Reversibility

Building Maintainability

Resource Recovery

The building Characteristics

Collaboration & Partnership/Industrial Symbiosis

Presence of Motivated/Capable Team

Economic Viability of Basic Strategies

New Business Models

Policy/Legislative Support

Enabling/Digital Technologies

Location of the project

Certification

Social acceptance

1. Design Standardization

2. Separation of the Building Layers (e.g. Separated Walls)

3. Open Floor Plan

4. Provision of Multi-Purpose Spaces

5. Modularization of Spatial Configuration (Layout)

6. Utilization of Standardized Building Products

7. Provision of a Core for Building Services

8. Design for Surplus Capacity

9. Decentralization of Design

10. Design for a Mixed Use (Multifunctionality)

11. Utilization of Secondary (Reused/Recycled) Material

12. Utilization of Biobased (Biological) Material

13. Utilization of Circular (Reusable/Recyclable) Material

14. Alignment of the Interconnection Between the Floor Plans

15. Alignment of the Building Design with the Property Portfolio

16. Utilization of Adjustable Building Components

17. Utilization of Dismountable Building Components

18. Provision of Sharable Spaces

19. Utilization of Renewable Energy Technologies

20. Enabling the Use of Natural Lighting/Ventilation

21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)

22. Utilization of Water Recovery System

23. Provision of Sharable Facilities

24. Application of (or update of) Material Passports

25. Procurement of the Service of Building Products

26. Selective Dismantling

27. Send Back Discarded Material for Reuse/Recycling

28. Repurpose Old Building Materials/Products

29. Product Exchange

30. Implementation of Proactive/Predictive Maintenance

31. Repair of Old Building Components

~~32. Preservation of Monumental/Old Parts~~

33. Utilization of Rented-Second-Hand Products from CE Marketplace

Active Strategies

Operational Strategies

Literature-Based Strategy/Factor

Literature- and Practice-Based Strategy/Factor

Practice-Based Strategy/Factor

CO-Creation-Based Strategy/Factor

✖ Co-Creation-Based Linking

✖ Theory-Practice-Based Linking

Natural Acceptance If we can whole over there

Depends on the perspective: Design team, Building owner, investor

Category

design not

How big?

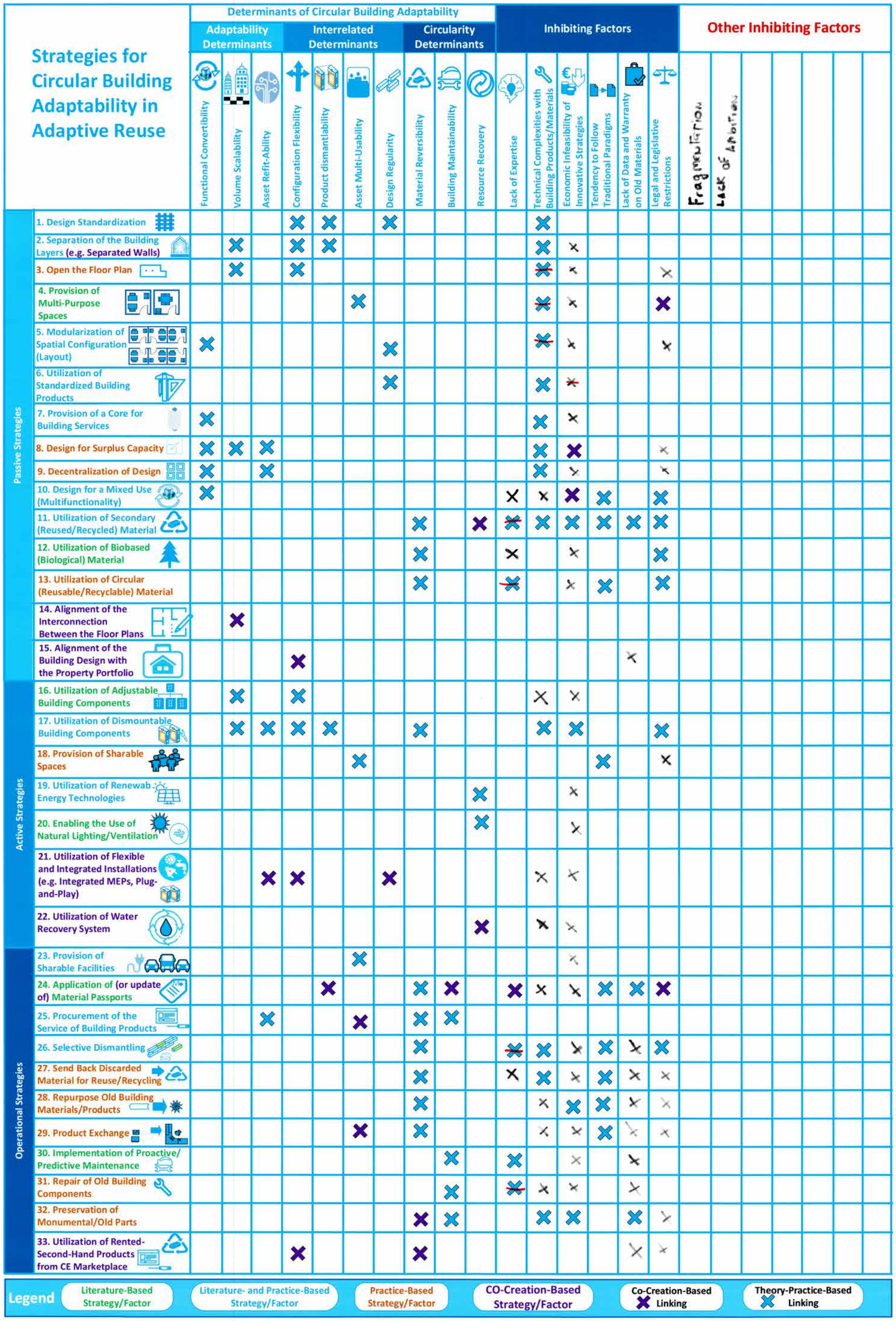
strategies influence each other

Combine

32 is enabling factor

APPENDIX D

Outcomes of validating and collaboratively expanding the inhibiting factors



	Strategies for Circular Building Adaptability in Adaptive Reuse	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation	Lack of Ambition					
		Determinants of Circular Building Adaptability										Inhibiting Factors						Other Inhibiting Factors						
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants															
Passive Strategies	1. Design Standardization				✕	✕		✕					✕											
	2. Separation of the Building Layers (e.g. Separated Walls)		✕		✕	✕							✕	✕										
	3. Open the Floor Plan		✕		✕								~~✕~~	✕			✕							
	4. Provision of Multi-Purpose Spaces						✕						~~✕~~	✕			✕							
	5. Modularization of Spatial Configuration (Layout)	✕						✕					~~✕~~	✕			✕							
	6. Utilization of Standardized Building Products							✕					✕	~~✕~~										
	7. Provision of a Core for Building Services	✕											✕	✕										
	8. Design for Surplus Capacity	✕	✕	✕									✕	✕			✕							
	9. Decentralization of Design	✕		✕									✕	✕			✕							
	10. Design for a Mixed Use (Multifunctionality)	✕										✕	✕	✕	✕		✕							
	11. Utilization of Secondary (Reused/Recycled) Material								✕		✕	~~✕~~	✕	✕	✕	✕	✕							
	12. Utilization of Biobased (Biological) Material								✕			✕		✕			✕							
	13. Utilization of Circular (Reusable/Recyclable) Material								✕			~~✕~~		✕	✕		✕							
	14. Alignment of the Interconnection Between the Floor Plans		✕																					
	15. Alignment of the Building Design with the Property Portfolio				✕											✕								
Active Strategies	16. Utilization of Adjustable Building Components		✕		✕								✕	✕										
	17. Utilization of Dismountable Building Components		✕	✕	✕	✕			✕				✕	✕			✕							
	18. Provision of Sharable Spaces						✕								✕		✕							
	19. Utilization of Renewable Energy Technologies										✕			✕										
	20. Enabling the Use of Natural Lighting/Ventilation										✕			✕										
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)			✕	✕			✕					✕	✕										
	22. Utilization of Water Recovery System										✕		✕	✕										
Operational Strategies	23. Provision of Sharable Facilities						✕							✕										
	24. Application of (or update of) Material Passports					✕			✕	✕		✕	✕	✕	✕	✕	✕							
	25. Procurement of the Service of Building Products			✕			✕		✕	✕														
	26. Selective Dismantling								✕			~~✕~~	✕	✕	✕	✕	✕							
	27. Send Back Discarded Material for Reuse/Recycling								✕			✕	✕	✕	✕	✕	✕							
	28. Repurpose Old Building Materials/Products								✕				✕	✕	✕	✕	✕							
	29. Product Exchange						✕		✕				✕	✕	✕	✕	✕							
	30. Implementation of Proactive/Predictive Maintenance									✕		✕		✕		✕								
	31. Repair of Old Building Components									✕		~~✕~~	✕	✕		✕								
	32. Preservation of Monumental/Old Parts								✕	✕			✕	✕		✕	✕							
	33. Utilization of Rented-Second-Hand Products from CE Marketplace				✕				✕							✕	✕							

Legend
- Literature-Based Strategy/Factor
- Literature- and Practice-Based Strategy/Factor
- Practice-Based Strategy/Factor
- CO-Creation-Based Strategy/Factor
- ✕ Co-Creation-Based Linking
- ✕ Theory-Practice-Based Linking

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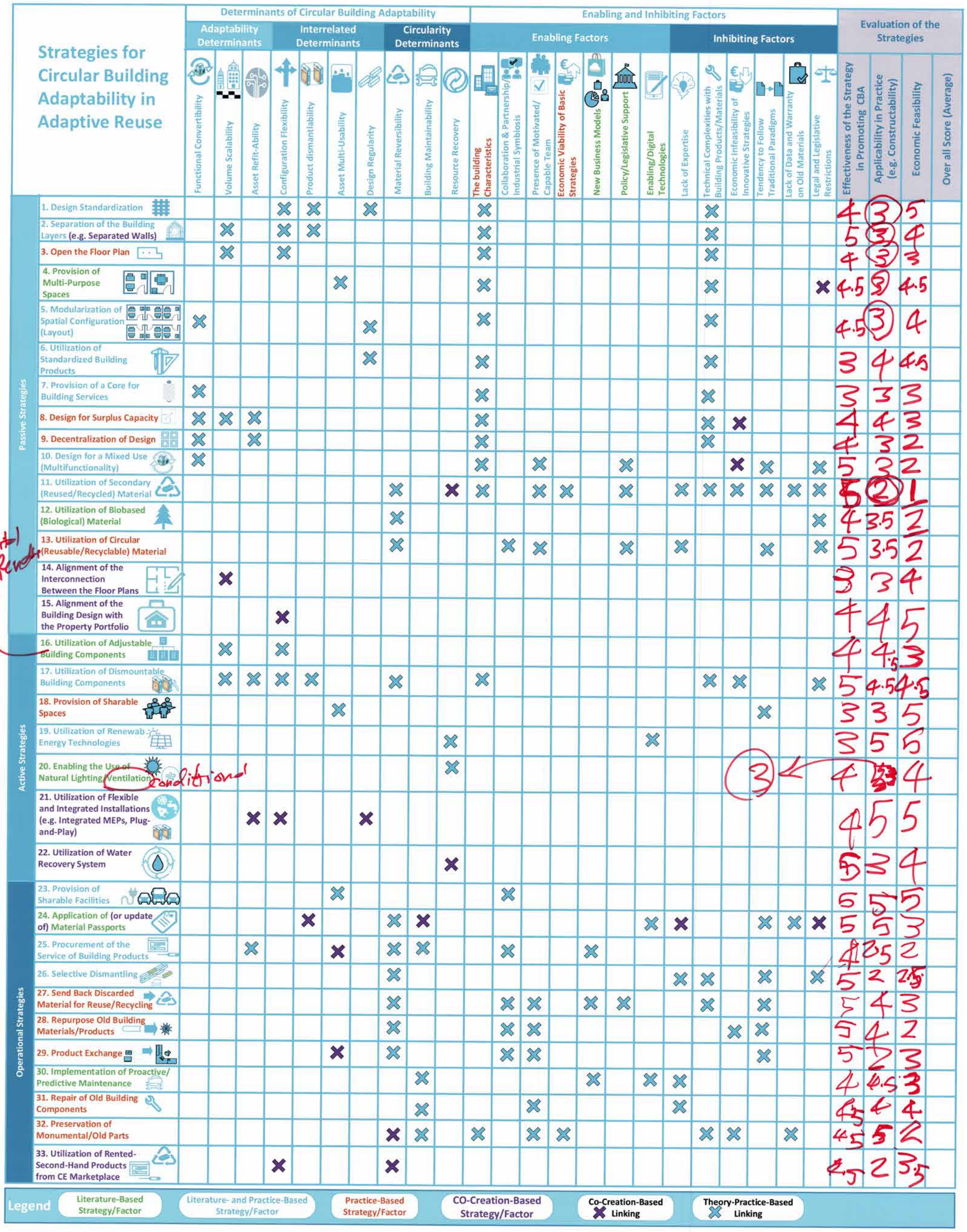
APPENDIX E

Outcomes of collaboratively rating the CBA strategies

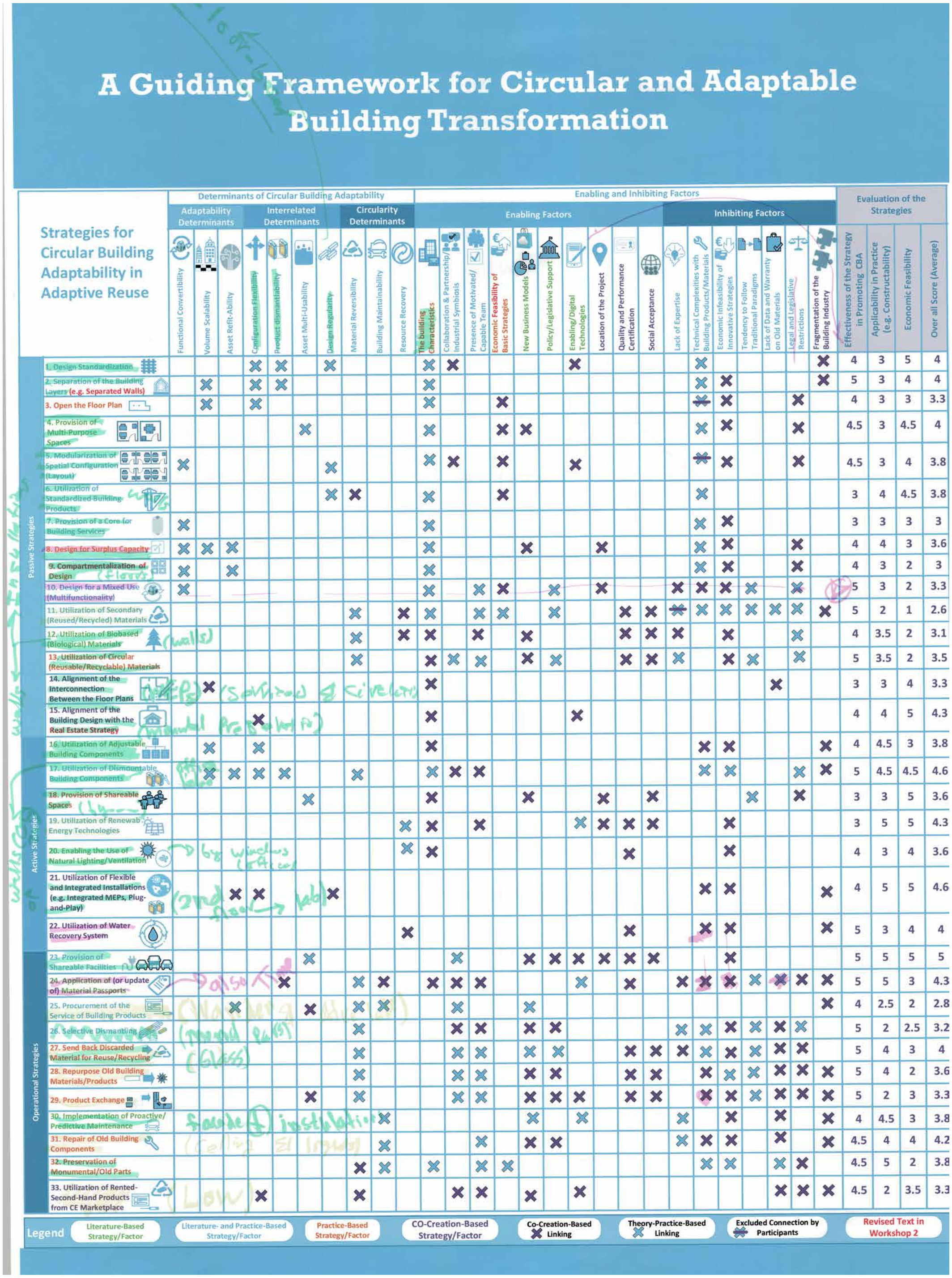


	Strategies for Circular Building Adaptability in Adaptive Reuse	Determinants of Circular Building Adaptability										Enabling and Inhibiting Factors													Evaluation of the Strategies			
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants			Enabling Factors							Inhibiting Factors									
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	The building Characteristics	Collaboration & Partnership/Industrial Symbiosis	Presence of Motivated/Capable Team	Economic Viability of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
Passive Strategies	1. Design Standardization				✕	✕		✕				✕								✕					4	③	5	
	2. Separation of the Building Layers (e.g. Separated Walls)		✕		✕	✕						✕								✕					5	③	4	
	3. Open the Floor Plan		✕		✕							✕								✕					4	③	3	
	4. Provision of Multi-Purpose Spaces						✕					✕								✕				✖	4.5	③	4.5	
	5. Modularization of Spatial Configuration (Layout)	✕						✕				✕								✕					4.5	③	4	
	6. Utilization of Standardized Building Products							✕				✕								✕					3	4	4.5	
	7. Provision of a Core for Building Services	✕										✕								✕					3	3	3	
	8. Design for Surplus Capacity	✕	✕	✕								✕								✕	✖				4	4	3	
	9. Decentralization of Design	✕		✕								✕								✕					4	3	2	
	10. Design for a Mixed Use (Multifunctionality)	✕										✕		✕			✕				✖	✕		✕	5	3	2	
	11. Utilization of Secondary (Reused/Recycled) Material								✕		✖	✕		✕	✕		✕		✕	✕	✕	✕	✕	✕	5	②	1	
	12. Utilization of Biobased (Biological) Material								✕															✕	4	3.5	2	
	Capital expenditure 13. Utilization of Circular (Reusable/Recyclable) Material								✕				✕	✕			✕		✕			✕		✕	5	3.5	2	
	14. Alignment of the Interconnection Between the Floor Plans		✖																						3	3	4	
	15. Alignment of the Building Design with the Property Portfolio				✖																				4	4	5	
Active Strategies	16. Utilization of Adjustable Building Components		✕		✕																				4	4.5	3	
	17. Utilization of Dismountable Building Components		✕	✕	✕	✕			✕			✕								✕	✕			✕	5	4.5	4.5	
	18. Provision of Sharable Spaces						✕															✕			3	3	5	
	19. Utilization of Renewab Energy Technologies										✕							✕							3	5	5	
	20. Enabling the Use of Natural Lighting/Ventilation conditional										✕											③			4	3	4	
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)			✖	✖			✖																	4	5	5	
	22. Utilization of Water Recovery System										✖														5	3	4	
Operational Strategies	23. Provision of Sharable Facilities						✕						✕												5	5	5	
	24. Application of (or update of) Material Passports					✖			✕	✖								✕	✖			✕	✕	✖	5	5	3	
	25. Procurement of the Service of Building Products			✕			✖		✕	✕			✕			✕									4	3.5	2	
	26. Selective Dismantling								✕										✕	✕		✕		✕	5	2	2.5	
	27. Send Back Discarded Material for Reuse/Recycling								✕				✕	✕		✕	✕			✕		✕			5	4	3	
	28. Repurpose Old Building Materials/Products								✕				✕	✕							✕	✕			5	4	2	
	29. Product Exchange						✖		✕				✕	✕								✕			5	2	3	
	30. Implementation of Proactive/Predictive Maintenance									✕						✕		✕	✕						4	4.5	3	
	31. Repair of Old Building Components									✕				✕					✕						4.5	4	4	
	32. Preservation of Monumental/Old Parts								✖	✕		✕		✕	✕					✕	✕		✕		4.5	5	2	
	33. Utilization of Rented-Second-Hand Products from CE Marketplace				✖				✖																4.5	2	3.5	

Legend: Literature-Based Strategy/Factor; Literature- and Practice-Based Strategy/Factor; Practice-Based Strategy/Factor; CO-Creation-Based Strategy/Factor; Co-Creation-Based ✖ Linking; Theory-Practice-Based ✕ Linking

APPENDIX F

Mapping the CBA strategies to the case project



A Guiding Framework for Circular and Adaptable Building Transformation

	Strategies for Circular Building Adaptability in Adaptive Reuse	Determinants of Circular Building Adaptability										Enabling and Inhibiting Factors																	Evaluation of the Strategies			
		Adaptability Determinants			Interrelated Determinants				Circularity Determinants			Enabling Factors										Inhibiting Factors										
		Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product dismantlability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	The building Characteristics	Collaboration & Partnership/ Industrial Symbiosis	Presence of Motivated/ Capable Team	Economic Feasibility of Basic Strategies	New Business Models	Policy/Legislative Support	Enabling/Digital Technologies	Location of the Project	Quality and Performance Certification	Social Acceptance	Lack of Expertise	Technical Complexities with Building Products/Materials	Economic Infeasibility of Innovative Strategies	Tendency to Follow Traditional Paradigms	Lack of Data and Warranty on Old Materials	Legal and Legislative Restrictions	Fragmentation of the Building Industry	Effectiveness of the Strategy in Promoting CBA	Applicability in Practice (e.g. Constructability)	Economic Feasibility	Over all Score (Average)
Passive Strategies	1. Design Standardization				✕	✕		✕				✕	✖					✖					✕					✖	4	3	5	4
	2. Separation of the Building Layers (e.g. Separated Walls)		✕		✕	✕						✕											✕	✖				✖	5	3	4	4
	3. Open the Floor Plan		✕		✕							✕			✖								~~✕~~	✖			✖		4	3	3	3.3
	4. Provision of Multi-Purpose Spaces						✕					✕			✖	✖							✕	✖			✖		4.5	3	4.5	4
	5. Modularization of Spatial Configuration (Layout)	✕						✕				✕	✖		✖			✖					~~✕~~	✖			✖		4.5	3	4	3.8
	6. Utilization of Standardized Building Products							✕	✖			✕			✖								✕						3	4	4.5	3.8
	7. Provision of a Core for Building Services	✕										✕											✕	✖					3	3	3	3
	8. Design for Surplus Capacity	✕	✕	✕								✕				✖			✖				✕	✖			✖		4	4	3	3.6
	9. Compartmentalization of Design (Floors)	✕		✕								✕											✕	✖			✖		4	3	2	3
	10. Design for a Mixed Use (Multifunctionality)	✕										✕		✕	✖		✕		✖			✖	✖	✖	✕		✕		5	3	2	3.3
	11. Utilization of Secondary (Reused/Recycled) Materials								✕		✖	✕		✕	✕		✕			✖	✖	~~✕~~	✕	✕	✕	✕	✕	✖	5	2	1	2.6
	12. Utilization of Biobased (Biological) Materials (walls)								✕		✖	✖		✖		✖				✖	✖	✖		✖			✕		4	3.5	2	3.1
	13. Utilization of Circular (Reusable/Recyclable) Materials								✕			✖	✕	✕		✖	✕			✖	✖	✕		✖	✕		✕		5	3.5	2	3.5
	14. Alignment of the Interconnection Between the Floor Plans		✖									✖														✖			3	3	4	3.3
	15. Alignment of the Building Design with the Real Estate Strategy				✖							✖						✖											4	4	5	4.3
Active Strategies	16. Utilization of Adjustable Building Components		✕		✕							✖											✖	✖				✖	4	4.5	3	3.8
	17. Utilization of Dismountable Building Components		✕	✕	✕	✕			✕			✕	✖	✖									✕	✕			✕	✖	5	4.5	4.5	4.6
	18. Provision of Shareable Spaces						✕					✖				✖			✖		✖				✕		✖		3	3	5	3.6
	19. Utilization of Renewab Energy Technologies										✕	✖		✖				✕	✖	✖	✖			✖					3	5	5	4.3
	20. Enabling the Use of Natural Lighting/Ventilation → by windows										✕	✖								✖				✖					4	3	4	3.6
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play) (2nd floor → lab)			✖	✖			✖															✖	✖				✖	4	5	5	4.6
	22. Utilization of Water Recovery System										✖									✖			✖	✖				✖	5	3	4	4
Operational Strategies	23. Provision of Shareable Facilities						✕						✕			✖	✖	✖	✖	✖	✖			✖					5	5	5	5
	24. Application of (or update of) Material Passports					✖			✕	✖		✖	✖	✖				✕		✖		✖	✖	✖	✕	✖	✖	✖	5	5	3	4.3
	25. Procurement of the Service of Building Products			✕			✖		✕	✕			✕			✕												✖	4	2.5	2	2.8
	26. Selective Dismantling								✕				✖	✖		✖	✖					✕	✕	✖	✕	✖	✕		5	2	2.5	3.2
	27. Send Back Discarded Material for Reuse/Recycling (Glass)								✕				✕	✕		✕	✕			✖	✖	✖	✕	✖	✕	✖	✖		5	4	3	4
	28. Repurpose Old Building Materials/Products								✕				✕	✕		✖	✖			✖	✖		✖	✕	✕	✖	✖	✖	5	4	2	3.6
	29. Product Exchange						✖		✕				✕	✕		✖	✖	✖		✖	✖		✖	✖	✕	✖	✖	✖	5	2	3	3.3
	30. Implementation of Proactive/ Predictive Maintenance (facade & installation)									✕						✕		✕				✕		✖		✖		✖	4	4.5	3	3.8
	31. Repair of Old Building Components									✕				✕		✖	✖					✕	✖	✖		✖		✖	4.5	4	4	4.2
	32. Preservation of Monumental/Old Parts								✖	✕		✕		✕	✕								✕	✕		✕	✖		4.5	5	2	3.8
	33. Utilization of Rented-Second-Hand Products from CE Marketplace (Low)				✖				✖				✖	✖		✖		✖								✖	✖	✖	4.5	2	3.5	3.3

Legend: Literature-Based Strategy/Factor | Literature- and Practice-Based Strategy/Factor | Practice-Based Strategy/Factor | CO-Creation-Based Strategy/Factor | Co-Creation-Based ✖ Linking | Theory-Practice-Based ✕ Linking | Excluded Connection by ~~✕~~ Participants | Revised Text in Workshop 2

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APPENDIX G

In-depth description of the CBA strategies

Passive CBA strategies

S1. Design standardization

- *Strategy description*: Unitizing the design of building layout and compositions, in terms of their geometry and dimensions, in a repetitive and unitized manner.
- *Example(s)*: Standardizing the layout and types of walls, installations, and openings.
- *Advantages*: Standardizing the dimensions and types of products can be economically feasible, due to the repetitiveness of these physical assets.
- *Possible disadvantages/challenges*: Design standardization could be restricted in adaptive reuse projects by the original configuration of the building, especially in monumental buildings.

S2. Separation of the building layers

- *Strategy description*: Composing and aligning the physical layers of the building in a separate manner corresponding to their expected service life
- *Example(s)*: Using dry connections in connecting the finishes, installations and other layers instead of wet connections.
- *Advantages*: Separating the building layers can ease their removals and reuse in the long term; thereby saving costs and reducing waste in the long term.
- *Possible disadvantages/challenges*: Separating the building layers could be hindered by the original composition of materials in adaptive reuse projects of old buildings.

S3. Open the floor plan

- *Strategy description*: Providing an open space within the floor plan that can be divided afterward based on the changing requirements of users.
- *Example(s)*: Providing an open-office space within the floor plan, instead of individual offices, which can be adapted or reconfigured by the tenants.

- *Advantages*: Providing an open office space can provide the users with the flexibility of configuring the open space afterward based on the changing needs.
- *Possible disadvantages/challenges*: An open office space may lack privacy of speech.

S4. Provision of multi-purpose spaces

- *Strategy description*: Providing a spatial zone or room(s) within the building that can be shared and used by many users
- *Example(s)*: Providing a multi-use space that can be used as a working space and a meeting room.
- *Advantages*: Proving multi-purpose spaces in a building maximizes the space efficiency, as these multi-purpose spaces can be used following a programmed schedule among the users; thereby reducing the need for individual and different spaces.
- *Possible disadvantages/challenges*: Providing multipurpose spaces requires predicting the space utilization profile as well as a definition of the specific users who can have access to those spaces.

S5. Modularization of spatial configuration

- *Strategy description*: Configuring the spatial layout in a manner consisting of repetitive modules.
- *Example(s)*: Configuring the floor plan in a manner that consists of a regular, repetitive, and unitized type and number of spaces.
- *Advantages*: Having a modular configuration of spaces can save costs spent on finishes and installations due to the reactiveness of the layout and size of spaces while facilitating accommodating other functions that require a repetitive layout of spaces (e.g. hotels, apartments, offices, schools, and healthcare buildings).
- *Possible disadvantages/challenges*: Modularizing the spatial configuration can be impossible in maladaptive or irregular structures, or impeded by the structural elements of the building.

S6. Utilization of standardized building products

- *Strategy description*: Utilizing building products that have standardized size and quality.
- *Example(s)*: Using standardized doors, ceilings and partitions throughout the building.
- *Advantages*: Using standardized building products can be economically feasible when the building accommodates a consistent and symmetrical design while facilitating the reuse of a large number of products in the long term.
- *Possible disadvantages/challenges*: Using standardized building products can be incompatible with old buildings, due to special and physical limitations associated with the original design of these buildings.

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S7. Provision of a core for building services

- *Strategy description*: Providing a core in the building that vertically brings together the building services.
- *Example(s)*: Providing a service core in the building that brings and connects the MEP systems and circulation means together.
- *Advantages*: Having a service core in the building can save the cost of extending services for individual zones, facilitate maintenance and repair (M&R) works, and pave the way for future replacements and alterations based on the changing needs of users.
- *Possible disadvantages/challenges*: Providing a service core could be impossible in old, irregular, or maladaptive buildings as well as infeasible in small buildings.

S8. Design for surplus capacity

- *Strategy description*: Design the building and its system for extra capacity, exceeding the project requirements, so that future demands can be met.
- *Example(s)*: Oversizing dimensions of spaces, vertically or horizontally, and providing technical systems with a capacity that exceeds the building demand.
- *Advantages*: Having a surplus capacity facilitates meeting the growing demands of users in the long term and accommodating other functions that require more technical performance
- *Possible disadvantages/challenges*: This strategy can be impossible in existing buildings because of the original design, or impractical when future additions are not possible. Furthermore, this strategy increases expenditures during the redevelopment phase of an existing building.

S9. Compartmentalization of design

- *Strategy description*: Dividing the building into independent compartments (zones), either horizontally or vertically, with their technical systems so that future changes can be easily made on the compartment level.
- *Example(s)*: Dividing the building into independent zones, vertically and/or horizontally, in which each zone would have its supply of services and circulation means.
- *Advantages*: Individual compartments can be repurposed and adapted easily in the long term in response to the changing needs and market dynamics.
- *Possible disadvantages/challenges*: The applicability of this strategy can be limited in existing buildings due to restrictions associated with the original design. Furthermore, compartmentalization may require providing more services per zone, thereby adding more expenditures to the redevelopment cost.

S10. Design for a mixed-use

- *Strategy description*: Configure the building in a manner that accommodates different functions and can facilitate future repurposing.
- *Example(s)*: Accommodating residential and non-residential uses in the building.
- *Advantages*: From a property investment point of view, this strategy reduces property risks through diversifying sources of income, while reducing possible property vacancy in such kind of mixed-use buildings during market volatility.
- *Possible disadvantages/challenges*: This strategy might be impossible in monofunctional locations, or restricted by the zoning policies.

S11. Utilization of secondary (reused/recycled) materials/products

- *Strategy description*: The use of second-hand products or secondary materials in the new design
- *Example(s)*: Using second-hand furniture items, such as second-hand office fitouts, and installations such as noise insulations.
- *Advantages*: The cost of using second-hand building products can be cheaper than the cost of using new products.
- *Possible disadvantages/challenges*: The performance of these products may not be as high as new products, also the compatibility and adequacy of these products can be limited against the requirements of the new design. Therefore, the alignment between using second-hand and new products is necessary.

S12. Utilization of biobased materials

- *Strategy description*: The use of components and products that are made of biological materials.
- *Example(s)*: Using biobased paint, insulations and components that are made out of biological materials (e.g. timber).
- *Advantages*: These products tend to have lower embodied energy.
- *Possible disadvantages/challenges*: Some of these products may not satisfy the applicable fire safety requirements.

S13. Utilization of circular (reusable/recyclable) materials/products

- *Strategy description*: Use of building products and components that are made of reusable and or recyclable materials
- *Example(s)*: Using furniture items and components that are made of wood (a biobased material), recyclable materials (e.g. steel), and reusable parts (e.g. wet and standardized connections).
- *Advantages*: These parts of these types of products can add value in the long term, as they can be sold out to reuse and recycling agencies while avoiding waste generation.
- *Possible disadvantages/challenges*: The reusability and recyclability of specific parts of these products may not be determinable or entirely possible.

S14. Alignment of the interconnection between the floor plans

- *Strategy description*: Coordinating the connection between the floor plans in terms of services and circulations.
- *Example(s)*: Locating the plumbing services, shafts, and elevators together in the same location on each floor.
- *Advantages*: Future space utilization and configuration rezoning can be further facilitated at the floor level by aligning the interconnection between the floor plans.
- *Possible disadvantages/challenges*: Fire safety restrictions, other municipal requirements, and physical constraints can limit aligning the interconnection between the floor plans.

S15. Alignment of the building design with the real estate strategy

- *Strategy description*: Alignment between the building design and the organizational business strategy.
- *Example(s)*: Providing different functions in the building as a means to diversify sources of organizational income.
- *Advantages*: The redevelopment of the adaptive reuse can be in an alignment of other organization- and business-related considerations; thereby prolonging the utility of the adapted building.
- *Disadvantages/challenges*: Implementing this strategy can be limited when the building is being redeveloped exclusively from a developer perspective.

Active CBA strategies

S16. Utilization of adjustable building components/products to users

- *Strategy description*: use of building products that are versatile and can fit the needs of individual users
- *Example(s)*: Using flexible fit-outs such as adjustable chairs, adjustable desks, and folding walls.
- *Advantages*: Adjustable items are user-centered assets, which can contribute to satisfying the preferences of individual users on a daily basis.
- *Possible disadvantages/challenges*: Some of the adjustable building products could be useless or overinvestment, such as folding walls; therefore providing this type of assets requires an understanding of the specific use pattern of the building spaces.

S17. Utilization of dismountable building components

- *Strategy description*: Using building components that can be easily dismantled.
- *Example(s)*: Providing demountable wall partitions and plug-and-play (PnP) installations and fit-outs that can be easily dismantled and reused in other locations.

- *Advantages*: Using demountable building products can facilitate accommodating future changes, as per the user/owner requirements, while facilitating the reuse of these products in the future; thereby reducing waste generation.
- *Possible disadvantages/challenges*: The reusability of the demountable products in other projects afterward is not always possible or guaranteed.

S18. Provision of shareable spaces

- *Strategy description*: Providing spaces or rooms within the building that can be used by different users of the building
- *Example(s)*: Providing shareable lounges, toilets, kitchens, and meeting rooms that can be used by different users/tenants of the building.
- *Advantages*: Increasing the efficiency of space utilization and reducing the need for more spaces.
- *Possible disadvantages/challenges*: This strategy might not always be accepted or preferable by all individuals or organizations; therefore understanding the profile of the end user is necessary.

S19. Utilization of renewable energy technologies

- *Strategy description*: Using renewable resource-based systems to generate building electricity
- *Example(s)*: PV panels, PVT panels, and geothermal pumps.
- *Advantages*: Saving the costs spent on the operational energy, while contributing to reducing using of non-renewable energy sources.
- *Possible disadvantages/challenges*: These systems could require high investment costs, while their effectiveness could be influenced by the weather conditions as well as physical constraints related to the building and its neighbouring buildings.

S20. Enabling the use of natural lighting/ventilation

- *Strategy description*: Facilitating using natural lighting and ventilation instead of artificial lighting and ventilation systems.
- *Example(s)*: Providing openable and accessible windows in the interior spaces to provide the user with the means of having natural lighting and ventilation during the day time.
- *Advantages*: This strategy contributes to resource renewability, as using natural lighting/ventilation is a way of using resources in a manner that reduces the need to consume non-renewable resources. In addition, natural lighting and ventilation contribute to increasing user stratification with the thermal and visual comfort-related indicators, respectively.
- *Possible disadvantages/challenges*: Facilitating using natural lighting and ventilation could be limited and hindered by the original design of the building.

S21. Utilization of flexible and integrated building installations

- *Strategy description*: Using flexible building installations that bring together different systems.
- *Example(s)*: Using plug-and-play office cells that include noise insulation and lights. Another example is using plug-and-play (PnP) wall partitions that integrate other services into the wall composition.
- *Advantages*: Providing this type of installation can contribute to coping with the fragmentation between different building systems while facilitating the adaptability of building spaces to the users. Furthermore, the reusability of this type of product is high, as these products may include different parts that can be reused or recycled at the end of the service life of such kind of products.
- *Possible disadvantages/challenges*: This type of installation may require a higher investment cost, while the adaptability of this type of product is not always needed by the user.

S22. Utilization of water recovery system

- *Strategy description*: Using a system that can treat and circulate the water within the building.
- *Example(s)*: Using a system that can treat and circulate the used water for other purposes in the building.
- *Advantages*: Contributing to promoting circularity in the consumption of water as a resource.
- *Possible disadvantages/challenges*: This strategy can be economically and technically ineffective.

Operational CBA strategies

S23. Provision of shareable facilities

- *Strategy description*: Provision of facilities, such as products, that can be used by different users.
- *Example(s)*: Providing shareable charging stations, pantries, and office machines.
- *Advantages*: This strategy can maximize the efficiency of using existing assets by the means of maximizing the number of users of a particular asset; thereby reducing the need for providing more assets.
- *Possible disadvantages/challenges*: The applicability of this strategy is limited when there are different types of users/tenants in the building.

S24. Application of (or update of) material passports

- *Strategy description*: Documenting the materials used in the building and their specifications.
- *Example(s)*: Register the newly added products and information about their properties and providers.
- *Advantages*: Having documentation of the used building products and materials in the building eases the reuse or selling of these assets afterward.
- *Possible disadvantages/challenges*: Applying material passports could be expensive and difficult in old buildings owing to the lack of records of the available materials.

S25. Procurement of the service of building products

- *Strategy description*: Purchasing building products in a form of service instead of owning the products
- *Example(s)*: Leasing elevators, office fit-outs, and lights.
- *Advantages*: There is an economic advantage of providing building products as a service, namely saving the costs of unexpected repairs. Obsolescence-wise, providing building products as a service facilitates replacing these products with new ones or returning them to the provider; thereby avoiding waste generation.
- *Possible disadvantages/challenges*: Providers of this type of product are limited.

S26. Selective dismantling

- *Strategy description*: The process of removing building components and products part by part to avoid their damage and facilitate their reuse
- *Example(s)*: Removing old building partitions, ceiling tiles, and lighting fixtures systematically by demounting them part by part without inflicting damage.
- *Advantages*: Selective dismantling increases the opportunity to reuse or sell the demounted products while reducing the need for implementing repair of damages caused by demolishing old building parts.
- *Possible disadvantages/challenges*: This strategy can be difficult when removing building products that are attached to monumental elements by wet connections.

S27. Send back discarded material for reuse/recycling

- *Strategy description*: Sending back discarded materials and products to recycling or reuse firms; thereby avoiding waste development.
- *Example(s)*: Sending back old ceiling tiles, plumbing fixtures, lighting boxes, doors, and wall panels to reuse firms.
- *Advantages*: Sending back old building materials for reuse and recycling may constitute an opportunity to generate an economic income.
- *Possible disadvantages/challenges*: Old building products could deteriorate in old buildings; therefore, providers of second-hand products might be unwilling to purchase this type of product.

S28. Repurpose old building materials/products

- *Strategy description*: Reusing existing building materials or products in a manner that differs from the original purpose for which these products and materials were made.
- *Example(s)*: Reusing old products and materials as decoration elements.
- *Advantages*: Avoiding waste generation, and possibly preserving some products that constitute monumental elements in heritage buildings.
- *Possible disadvantages/challenges*: Repurposing old building materials and products might be expensive, possibly accounting for the same cost of using new materials and products.

S29. Products exchange

- *Strategy description*: Exchanging extra or surplus building products with another second-hand or new products, instead of sending those products to waste
- *Example(s)*: Exchanging old building products with other second-hand/new building products. For example, exchanging old products and materials with other second-hand ones through providers of second-hand building materials.
- *Advantages*: Product exchange may constitute an opportunity to save costs spent in purchasing new products while avoiding waste development.
- *Possible disadvantages/challenges*: Old products could be physically deteriorated in old buildings; therefore, their exchange might be impossible. Furthermore, the alignment between the exchanged products might be a complex process due to differences of materials and lack of information.

S30 Implementation of proactive/predictive maintenance

- *Strategy description*: Implementing maintenance on the building on a regular basis to prevent any form of building collapse or deterioration.
- *Example(s)*: Adoption and implementation of periodic maintenance of all systems and components in the project.
- *Advantages*: Prolong the longevity and promote the reusability of existing systems and building components.
- *Possible disadvantages/challenges*: The maintenance of old buildings might be an expensive and complex process.

S31. Repair of old building components/systems

- *Strategy description*: Exchanging extra or surplus building products with other second-hand or new products
- *Example(s)*: Repairing structural, construction, services, and other old building components systems, such as old wall panels, doors, and storing cabinets.
- *Advantages*: Repairing existing systems is a means to prolong the longevity of the physical assets, thereby reducing the need for material resources. It might be cost-effective for expensive systems – such as radiators.
- *Possible disadvantages/challenges*: Repair of old building systems might be expensive and infeasible for deteriorated assets; therefore, a condition assessment of these assets needs to be conducted.

S32. Preservation of monumental/old parts

- *Strategy description*: Preserving existing monumental components and products used in the building, both externally and internally.
- *Example(s)*: Retaining finishes, components, and products that constitute monumental parts in the building, such as classical windows, doors, and finishes.
- *Advantages*: Preserving monumental parts as a means for heritage conservation. It can be a means for acquiring municipal incentives.
- *Possible disadvantages/challenges*: Preserving monumental building parts might be incompatible with the characteristics and profile of the new use of the building.

S33. Utilization of rented-second-hand products from CE marketplaces

- *Strategy description*: Leasing second-hand building products instead of buying them
- *Example(s)*: Renting second-hand office fit-outs.
- *Advantages*: Low renting cost.
- *Possible disadvantages/challenges*: Limited number of providers of this type of product. The quality of the second-hand products might be low.

APPENDIX H

A hypothetical example of using the CBA-AR worksheet as a determining, assessment, and reporting tool

Example

Suppose that a developer who owns a vacant office building has worked with an architect to convert the vacant office into a mixed-use building by incorporating residential apartments, shops, and co-working spaces into the building configuration. After exploring the CBA strategies included in the CBA-AR framework, they selected 21 strategies to implement in the project, and therefore, they incorporated these strategies into the plan and definitive design of the project. Following are the selected strategies along with their practical solutions:

- Design standardization (of doors and windows).
- Separation of the building layers (by using dry connections in all services, installations, and fit-outs).
- Providing an open space as a co-working area on the first floor.
- Providing a multi-purpose hall on the ground floor.
- Modularizing the configuration of spaces and layout of MEPs.
- Utilization of standardized building products (MEP fixtures, wall panels, and office fit-outs)
- Providing two cores for building services (elevators and MEPs).
- Design for surplus capacity by oversizing the heating system and providing a rooftop extension
- Compartmentalization of design by dividing the floor plan horizontally into independent zones with their own MEP supply and other services.
- Design for mixed-use by using high-quality façade materials, oversizing the MEPs and providing residential and commercial uses within the building function.
- Utilization of biobased (biological) materials by using bio-based wall panels and desks.
- Utilization of circular materials/products by using reusable glass panels and frames.
- Alignment of the interconnection between the floor plans by coordinating and connecting all floors by a stair and elevator.
- Alignment of the building design with the real estate strategy by including different functions in the buildings as a means to diversify organizational income.
- Utilization of dismountable building components by using demountable lighting fixtures, demountable ceilings, demountable partitions, and PnP cubicles.
- Provision of shareable spaces by providing a shareable lounge and seating area in the building.
- Utilization of renewable energy technologies by using façade and rooftop PVs and geothermal heat pumps.
- Procurement of the service of building products by leasing the new elevators.
- Selective dismantling by selectively dismantling old curtain walls.
- Sending back the selectively dismantled curtain walls for reuse.
- Implementation of proactive maintenance of the MEP systems by adopting a maintenance program for all MEPs

The developer and architect would fill out the worksheet as shown in the example, and thereby, they determined the promotion of CBA, considering the corresponding building layers and R-measures from the R-ladder model. The 10 determinists of CBA have been promoted through four layers of the shearing layer model. Reflecting on the R-ladder model, the architect and developer have been able to achieve a high level of circularity, as 15 out of the 21 CBA strategies are exclusively related to the so-called smarter product use and manufacture

	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	
Passive Strategies	1. Design Standardization	Design	S4, S5. S6	Consisted use of walls, doors and windows	R2	
	2. Separation of the Building Layers (e.g. Separated Walls)	Design	S3, S4, S5, S6	Partitions are independents connected by dry connections	R2	
	3. Open the Floor Plan	Design	S5	Open office space	R2	
	4. Provision of Multi-Purpose Spaces	Design	S5	Spaces that can be used as offices and meeting rooms	R1	
	5. Modularization of Spatial Configuration (Layout)	Design	S4, S5	Unitized and repetitive pattern of rooms	R2	
	6. Utilization of Standardized Building Products	Design	S4, S5. S6	Using standardized doors, ceilings and partitions throughout the building	R2	
	7. Provision of a Core for Building Services	Design	S5	Central area providing an elevator and a shaft	R2	
	8. Design for Surplus Capacity	Design	S3, S4, S5	Oversizing spaces and systems	R1 and R0	
	9. Compartmentalization of Design	Design	S4, S5	The building is divided into independent zones	R1	
	10. Design for a Mixed Use (Multifunctionality)	Design	S3, S4, S5, S6	The building includes and can accommodate different function	R1	
	11. Utilization of Secondary (Reused/Recycled) Materials/Products	Design	S4, S5. S6	Using second hand furniture	R3 and R8	
	12. Utilization of Biobased (Biological) Materials	Design	S3, S4, S5. S6	Using timber-based products	R2	
	13. Utilization of Circular (Reusable/Recyclable) Materials/Products	Design	S3, S4, S5. S6	Glass panels can be reused and recycled at the end of their use	R2	
	14. Alignment of the Interconnection Between the Floor Plans	Design	S5	Horizontal zones are vertically coordinated with other zones through circulation means	-	
	15. Alignment of the Building Design with the Real Estate Strategy	Design	S5	The building horizontal zones are coordinated with other zones	-	

Legend R0- R2 = Smarter product use and manufacture

A hypothetical example of using the CBA-AR worksheet for exploring, determining, assessing, and reporting the promotion of CBA in a hypothetical adaptive reuse project

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	Determinants of Circular Building Adaptability										YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
	Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery					
				✕	✕		✕				✓			Doors and windows	
		✕		✕	✕						✓		Dry connections	Dry connections	Dry connections
		✕		✕							✓			Open co-working space on the FF	
						✕					✓			Multi-purpose hall	
	✕						✕				✓		The layout of MEP systems is regular	Modular configuration of offices	
							✕	✕			✓		Standardized MEP fixtures	Standardized wall panels	Standardized office fit-outs
	✕										✓			Two cores accommodating lifts and MEPs	
	✕	✕	✕								✓		Oversizing the heating system	Rooftop extension	
	✕		✕								✓		Each floor has its own MEP supply	The floor are independent from each other	
	✕										✓	High quality façade materials	Oversizing the MEPs	Residential and commercial spaces	
								✕		✕					
								✕		✕	✓			Bio-based panels	Bio-based tables
								✕			✓			Reusable glass panels and frames	
		✕									✓			All floors are connected by a stair and elevator	
				✕							✓			Different functions are incorporated to diversify income	

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

A hypothetical example of using the CBA-AR worksheet as a determining, assessment, and reporting tool

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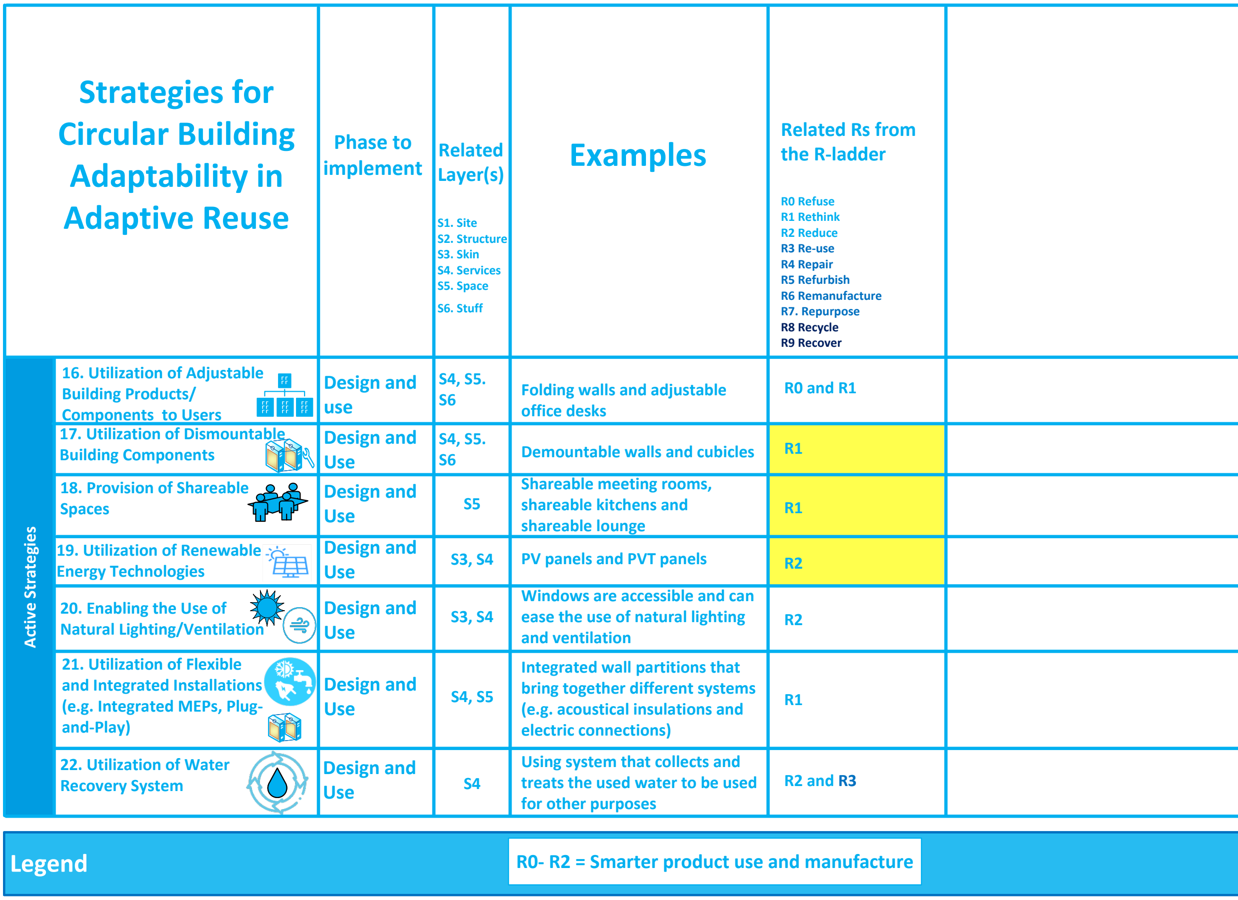

Strategies for Circular Building Adaptability in Adaptive Reuse		Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	
Active Strategies	16. Utilization of Adjustable Building Products/ Components to Users	Design and use	S4, S5. S6	Folding walls and adjustable office desks	R0 and R1	
	17. Utilization of Dismountable Building Components	Design and Use	S4, S5. S6	Demountable walls and cubicles	R1	
	18. Provision of Shareable Spaces	Design and Use	S5	Shareable meeting rooms, shareable kitchens and shareable lounge	R1	
	19. Utilization of Renewable Energy Technologies	Design and Use	S3, S4	PV panels and PVT panels	R2	
	20. Enabling the Use of Natural Lighting/Ventilation	Design and Use	S3, S4	Windows are accessible and can ease the use of natural lighting and ventilation	R2	
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)	Design and Use	S4, S5	Integrated wall partitions that bring together different systems (e.g. acoustical insulations and electric connections)	R1	
	22. Utilization of Water Recovery System	Design and Use	S4	Using system that collects and treats the used water to be used for other purposes	R2 and R3	

Legend

R0- R2 = Smarter product use and manufacture

A hypothetical example of using the CBA-AR worksheet for exploring, determining, assessing, and reporting the promotion of CBA in a hypothetical adaptive reuse project

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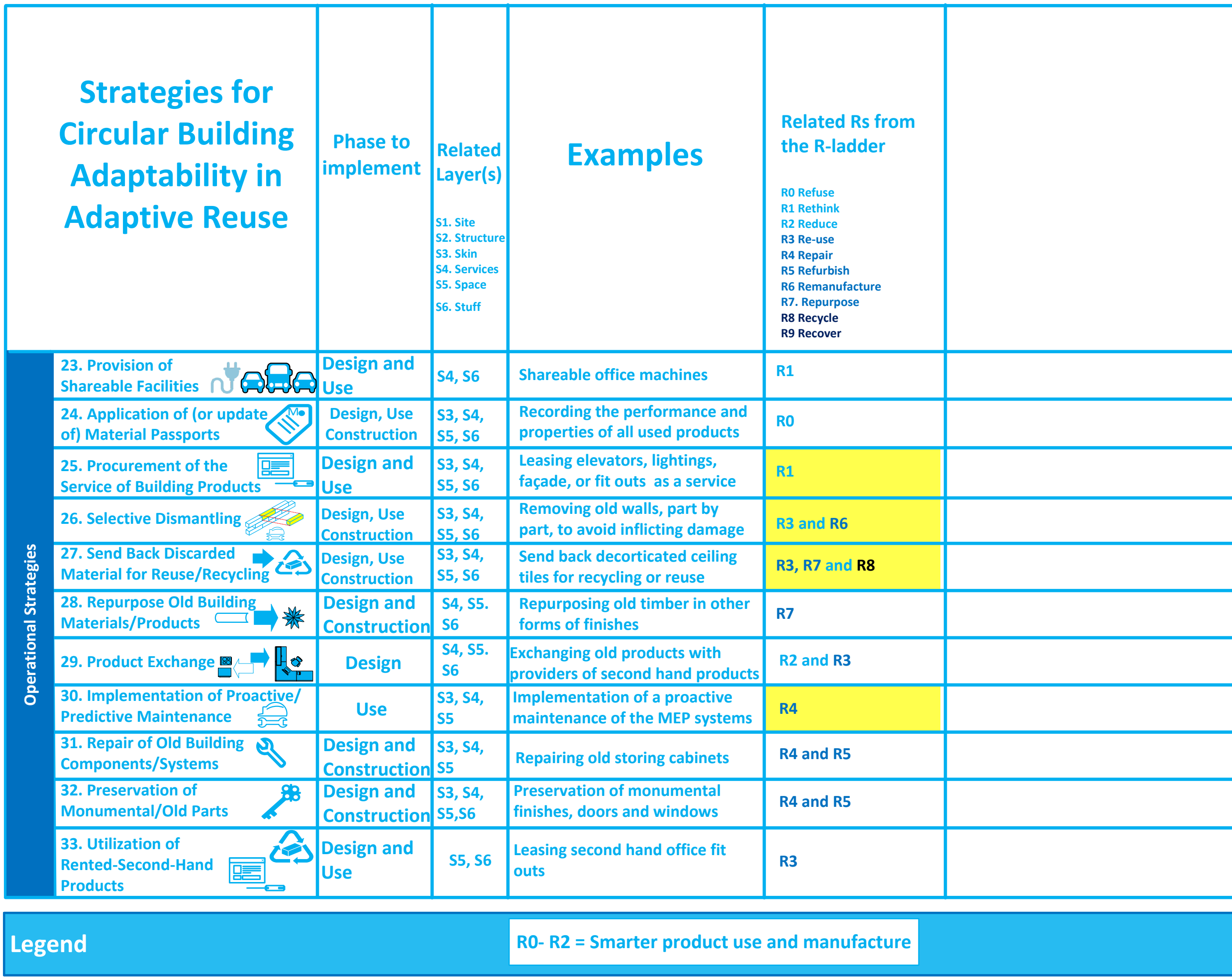
Determinants of Circular Building Adaptability														
Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
	✗		✗											
	✗	✗	✗	✗			✗			✓		Demountable lighting fixtures	Demountable ceiling and partitions	PnP cubicles
					✗					✓			Sharable lounge and seating area	
									✗	✓	Façade and rooftop PV	Geothermal heat pumps		
									✗					
		✗	✗			✗								
									✗					

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

A hypothetical example of using the CBA-AR worksheet as a determining, assessment, and reporting tool



	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover
Operational Strategies	23. Provision of Shareable Facilities	Design and Use	S4, S6	Shareable office machines	R1
	24. Application of (or update of) Material Passports	Design, Use Construction	S3, S4, S5, S6	Recording the performance and properties of all used products	R0
	25. Procurement of the Service of Building Products	Design and Use	S3, S4, S5, S6	Leasing elevators, lightings, façade, or fit outs as a service	R1
	26. Selective Dismantling	Design, Use Construction	S3, S4, S5, S6	Removing old walls, part by part, to avoid inflicting damage	R3 and R6
	27. Send Back Discarded Material for Reuse/Recycling	Design, Use Construction	S3, S4, S5, S6	Send back decorticated ceiling tiles for recycling or reuse	R3, R7 and R8
	28. Repurpose Old Building Materials/Products	Design and Construction	S4, S5. S6	Repurposing old timber in other forms of finishes	R7
	29. Product Exchange	Design	S4, S5. S6	Exchanging old products with providers of second hand products	R2 and R3
	30. Implementation of Proactive/ Predictive Maintenance	Use	S3, S4, S5	Implementation of a proactive maintenance of the MEP systems	R4
	31. Repair of Old Building Components/Systems	Design and Construction	S3, S4, S5	Repairing old storing cabinets	R4 and R5
	32. Preservation of Monumental/Old Parts	Design and Construction	S3, S4, S5,S6	Preservation of monumental finishes, doors and windows	R4 and R5
	33. Utilization of Rented-Second-Hand Products	Design and Use	S5, S6	Leasing second hand office fit outs	R3

Legend

R0- R2 = Smarter product use and manufacture

A hypothetical example of using the CBA-AR worksheet for exploring, determining, assessing, and reporting the promotion of CBA in a hypothetical adaptive reuse project

	Determinants of Circular Building Adaptability														
	Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
						✕						▨		▨	
					✕			✕	✕						
			✕			✕		✕	✕		✓		Leasing elevators		
								✕			✓	Selective dismantling of curtain walls			
								✕			✓	Sending back the old curtain walls for resue			
								✕				▨			
						✕		✕				▨			
									✕		✓		Adopting MEP maintenance program		▨
									✕						▨
								✕	✕						
				✕				✕				▨	▨		

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

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APPENDIX I

Using the CBA-AR worksheet as a determining, assessment, and reporting tool for the case project

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	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	
Passive Strategies	1. Design Standardization	Design	S4, S5. S6	Consisted use of walls, doors and windows	R2	
	2. Separation of the Building Layers (e.g. Separated Walls)	Design	S3, S4, S5, S6	Partitions are independents connected by dry connections	R2	
	3. Open the Floor Plan	Design	S5	Open office space	R2	
	4. Provision of Multi-Purpose Spaces	Design	S5	Spaces that can be used as offices and meeting rooms	R1	
	5. Modularization of Spatial Configuration (Layout)	Design	S4, S5	Unitized and repetitive pattern of rooms	R2	
	6. Utilization of Standardized Building Products	Design	S4, S5. S6	Using standardized doors, ceilings and partitions throughout the building	R2	
	7. Provision of a Core for Building Services	Design	S5	Central area providing an elevator and a shaft	R2	
	8. Design for Surplus Capacity	Design	S3, S4, S5	Oversizing spaces and systems	R1 and R0	
	9. Compartmentalization of Design	Design	S4, S5	The building is divided into independent zones	R1	
	10. Design for a Mixed Use (Multifunctionality)	Design	S3, S4, S5, S6	The building includes and can accommodate different function	R1	
	11. Utilization of Secondary (Reused/Recycled) Materials/Products	Design	S4, S5. S6	Using second hand furniture	R3 and R8	
	12. Utilization of Biobased (Biological) Materials	Design	S3, S4, S5. S6	Using timber-based products	R2	
	13. Utilization of Circular (Reusable/Recyclable) Materials/Products	Design	S3, S4, S5. S6	Glass panels can be reused and recycled at the end of their use	R2	
	14. Alignment of the Interconnection Between the Floor Plans	Design	S5	Horizontal zones are vertically coordinated with other zones through circulation means	-	
	15. Alignment of the Building Design with the Real Estate Strategy	Design	S5	The building horizontal zones are coordinated with other zones	-	

Legend	R0- R2 = Smarter product use and manufacture

Note: Green = promoted CBA determinants and R-ladder measures; Orange = newly added solutions to the project or expanded strategies/determinants

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	Determinants of Circular Building Adaptability														
	Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
				✗	✗		✗				✓		Acoustical installations	Wall panels	
		✗		✗	✗						✓			Partitions (20-25 years)	Fit-outs (10-15 years)
		✗		✗							✓			Hall	
						✗					✓			Multi-purpose hall (café, co-working, & congress)	
	✗						✗				✓			Modular configuration and consistent number of offices of	
							✗	✗			✓			Standardized partitions	
	✗										✓			Two cores for stairs, MEPs shafts and toilets	
	✗	✗	✗												
	✗		✗								✓			Each floor is a compartment	
	✗														
								✗		✗	✓				Second-hand fit-outs on the first floor
								✗		✗	✓			Biobased paintings and wooden studs	
								✗			✓			Removable wall partitions	
		✗									✓			Two services shafts are in the same location on each floor	
				✗							✓			Preserving heritage assets while diversifying sources of income	

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

	Strategies for Circular Building Adaptability in Adaptive Reuse	Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover
Active Strategies	16. Utilization of Adjustable Building Products/ Components to Users	Design and use	S4, S5. S6	Folding walls and adjustable office desks	R0 and R1
	17. Utilization of Dismountable Building Components	Design and Use	S4, S5. S6	Demountable walls and cubicles	R1
	18. Provision of Shareable Spaces	Design and Use	S5	Shareable meeting rooms, shareable kitchens and shareable lounge	R1
	19. Utilization of Renewable Energy Technologies	Design and Use	S3, S4	PV panels and PVT panels	R2
	20. Enabling the Use of Natural Lighting/Ventilation	Design and Use	S3, S4	Windows are accessible and can ease the use of natural lighting and ventilation	R2
	21. Utilization of Flexible and Integrated Installations (e.g. Integrated MEPs, Plug-and-Play)	Design and Use	S4, S5	Integrated wall partitions that bring together different systems (e.g. acoustical insulations and electric connections)	R1
	22. Utilization of Water Recovery System	Design and Use	S4	Using system that collects and treats the used water to be used for other purposes	R2 and **R3**

Legend R0- R2 = Smarter product use and manufacture

Note: Green = promoted CBA determinants and R-ladder measures; Orange = newly added solutions to the project or expanded strategies/determinants

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Determinants of Circular Building Adaptability														
Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery	YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
	✕		✕							✓				Adjustable cubicles and office fit-outs
	✕	✕	✕	✕			✕			✓			Demountable wooden partitions (ground floor)	
					✕					✓			Shareable hall, toilets, and meeting rooms	
									✕					
									✕	✓	Each office has an openable window			
		✕	✕			✕								
									✕					

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

Strategies for Circular Building Adaptability in Adaptive Reuse		Phase to implement	Related Layer(s) S1. Site S2. Structure S3. Skin S4. Services S5. Space S6. Stuff	Examples	Related Rs from the R-ladder R0 Refuse R1 Rethink R2 Reduce R3 Re-use R4 Repair R5 Refurbish R6 Remanufacture R7. Repurpose R8 Recycle R9 Recover	
Operational Strategies	23. Provision of Shareable Facilities	Design and Use	S4, S6	Shareable office machines	R1	
	24. Application of (or update of) Material Passports	Design, Use Construction	S3, S4, S5, S6	Recording the performance and properties of all used products	R0	
	25. Procurement of the Service of Building Products	Design and Use	S3, S4, S5, S6	Leasing elevators, lightings, façade, or fit outs as a service	R1	
	26. Selective Dismantling	Design, Use Construction	S3, S4, S5, S6	Removing old walls, part by part, to avoid inflicting damage	R3 and **R6**	
	27. Send Back Discarded Material for Reuse/Recycling	Design, Use Construction	S3, S4, S5, S6	Send back decorticated ceiling tiles for recycling or reuse	R3, R7 and **R8**	
	28. Repurpose Old Building Materials/Products	Design and Construction	S4, S5. S6	Repurposing old timber in other forms of finishes	R7	
	29. Product Exchange	Design	S4, S5. S6	Exchanging old products with providers of second hand products	R2 and **R3**	
	30. Implementation of Proactive/ Predictive Maintenance	Use	S3, S4, S5	Implementation of a proactive maintenance of the MEP systems	R4	
	31. Repair of Old Building Components/Systems	Design and Construction	S3, S4, S5	Repairing old storing cabinets	R4 and R5	
	32. Preservation of Monumental/Old Parts	Design and Construction	S3, S4, S5,S6	Preservation of monumental finishes, doors and windows	R4 and R5	
	33. Utilization of Rented-Second-Hand Products	Design and Use	S5, S6	Leasing second hand office fit outs	R3	

Legend R0- R2 = Smarter product use and manufacture

Note: Green = promoted CBA determinants and R-ladder measures; Orange = newly added solutions to the project or expanded strategies/determinants

	Determinants of Circular Building Adaptability										YES/ NO	S3. Skin	S4. Services	S5. Space	S6. Stuff
	Adaptability Determinants			Interrelated Determinants				Circularity Determinants							
	Functional Convertibility	Volume Scalability	Asset Refit-Ability	Configuration Flexibility	Product Demountability	Asset Multi-Usability	Design Regularity	Material Reversibility	Building Maintainability	Resource Recovery					
						✗					✓		Shareable charging stations		Shareable pantries
					✗			✗	✗						
			✗			✗		✗	✗						
								✗			✓		Selective dismantling of lighting fixtures	Selective dismantling of ceiling tiles	Selective dismantling of old vaults
								✗			✓	Old glass panels for reuse	Lighting fixtures	Ceiling tiles	
								✗			✓			Repurposing wooden ceiling to be used in the entrance	Repurposing vaults as cabinets on the ground floor
						✗		✗							
									✗		✓	Multi-year maintenance plan	Multi-year maintenance plan	Multi-year maintenance plan	
									✗		✓	Façade renovation	Repairing old radiators	Refurbishing old wall panels	
								✗	✗		✓	Façade, roof and main entrance door	Chandeliers and old radiators	Finishes used in the hall, corridors and stairs	Busts, wooden chairs, and reception tables and closets
				✗				✗							

R3- R7 = Extend life of product and its parts

R8- R9 = Useful application of materials

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Curriculum vitae

Hamida, Mohammad Basel

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Place of Birth: Dhahran, Saudi Arabia

Education

Nov. 2020 – Dec. 2024

Doctor of Philosophy (PhD) in Management in the Built Environment (MBE) (concentration on Real Estate Management)
Department of Management in the Built Environment (MBE), Faculty of Architecture and the Built Environment, Delft University of Technology, Delft (TU Delft), The Netherlands
Language of study: English
Working thesis title: *“Circular and Adaptable Building Transformation: Reconceptualization, Practice Exploration, Framework Co-Development, and Implementation”*
Research promoters: Prof. Hilde Remøy, Prof. Vincent Gruis, and Dr. Angela Greco

Sep. 2017 – Mar. 2020

Master of Science (MSc) in Architectural Engineering (emphasis on Facilities Engineering and Management)
Department of Architectural Engineering, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia
Language of study: English
Thesis title: *“Development of a Framework for the Effective Implementation of Building Adaptive Reuse throughout the Project Life Cycle in Saudi Arabia”*
Adviser: Prof. Mohammad A. Hassanain
GPA: 3.91/4.00 (Excellent)

Sep. 2012 – June 2017

Bachelor of Science (BSc) in the Building Engineering
Building Engineering Department, Imam Abdulrahman Bin Faisal University (formerly University of Dammam), Dammam, Saudi Arabia
Language of study: English
Senior project title: *“Energy Auditing of Educational Building in the Eastern Province of Saudi Arabia”*
Adviser: Dr. Faris Abdullah Almaziad

Academic/Research Experience

Nov. 2020 – Present

PhD Researcher, Real Estate Management (REM) chair, Department of Management in the Built Environment (MBE), Faculty of Architecture and the Built Environment (A+BE), Delft University of Technology (TU Delft), Delft, The Netherlands

Educational contributions include the following courses:

- Co-coordinating, co-supervising MSc students, chairing (as a delegate) thesis defenses, tutoring, and lecturing in *the MBE Graduation Lab (AR3MBE100 MSc 3)*.
  The following lectures were developed and given to the lab students:
  1. *Literature Review*
  2. *Laying the Groundwork for a Robust Research Design*
  3. *Writing a Coherent, Inviting, and Structured Introduction*
  4. *Research Methods*
  5. *Defining and Designing a Coherent Case Study Protocol*
- Establishing and video recording an entire module, as well as developing and grading exam questions in the *Building Economy (AR1MBE025*) course.
- Giving a lecture, titled "*Circular and Futureproof Adaptive Reuse: Lessons learned from Zandkasteel and other cases*", in the *Redesign of Complex Projects (AR2MBE015)* course to provide students with practical insights from demonstration circular transformation projects.

Sep. 2017 – May 2019

Grader, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia

Courses: Contracts and Specifications (ARE 459) and Construction Management (ARE 413)

Level: Undergraduate

Responsibilities: Grading homeworks and quizzes, and proctoring exams.

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Aug. 2013 –
Sep. 2014

Questionnaire interviewer, Saudi Aramco Chair for Traffic Safety, University of Dammam, Dammam, Saudi Arabia
Responsibilities: Conducting on-road questionnaires to investigate the perceptions as well as use of the seat belts among children and adults in the Eastern Province of Saudi Arabia.
Achievements: Assisting research team to complete two studies in transportation road safety.

Professional Experience

May 2024 –
Aug. 2024

Circularity Analyst Intern, BOEi, Delft, the Netherlands
Project: Reuse of a monumental office building – Het Groote Kantoor
Location: Wateringseweg 1 Delft, Delft, the Netherlands.
Responsibilities: Building a record of reusable products and materials and their reuse scenario, requesting quotations from suppliers of circular products, and doing NPV calculations of circular products.

May 2016 –
Aug. 2016

Trainee Building Engineer, Azmeel Contracting & Construction Corporation, Dammam, Saudi Arabia
Project: Establishment of the main administration building and the multi-purpose hall of Imam Abdulrahman Bin Faisal University
Location: East Campus, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia
Responsibilities: Documenting and overseeing the installation process of the precast panels, documenting the results of the slump tests of concrete castings, and reporting the shortcomings of the scaffolding.

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Recognitions, Honors, and Awards

Sep. 2024

Emerald’s Literati Award (outstanding paper award) for the paper, titled *“Circular building adaptability and its determinants – A literature review”*.

Previously, the authors wrote a reflection, titled “*Towards A Resource-Efficient and Future-Proof Built Environment*” to tell the story of conceptualizing the *circular building adaptability* concept.

Nov. 2019

Certificate of Appreciation from the chairman of Architectural Engineering Department, **King Fahd University of Petroleum and Minerals**

This was received as an acknowledgment of presenting a short course (workshop), titled “*Autodesk Revit 2019”*, for the department students between the 29th and 30th of October 2019, at the College of Environmental Design, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

Oct. 2019

Appreciation letter from the chairman of Architectural Engineering Department, **King Fahd University of Petroleum and Minerals**

This was received as an acknowledgement of presenting a short course (workshop), titled “*Microsoft Excel: Applications of the Software in the Architectural Engineering Domain”*, for the department students on the 4th of February 2019, at the College of Environmental Design, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

July 2016

Punctual Behavior Certificate, University of Lincoln

This was received during attendance of the *6th Annual University of Lincoln Summer School: Sustainable Energy & Building Technology; Resilient Architecture*, Lincoln, United Kingdom

July 2016

Hardwork & Outstanding Performance Certificate, University of Lincoln

This was received during attendance of the *6th Annual University of Lincoln Summer School: Sustainable Energy & Building Technology; Resilient Architecture*, Lincoln, United Kingdom

Sep. 2014

Appreciation letter from the head of Saudi Aramco Chair for Traffic Safety, University of Dammam

This was received as an acknowledgment of the strong sense of duty and responsibility displayed when assisting the research team in completing two transportation studies in Dammam, Saudi Arabia

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Extra-Curricular Activities

June, 2023

Recording an educational video, titled *“Exploring the Relation Between Circularity and Adaptability in Adaptive Reuse”*, Delft University of Technology, Delft, The Netherlands

The video was recorded for an educational platform, called Educators for Circularity, which is launched by the CBE Hub, Faculty of Architecture and the Built Environment, TU Delft, Delft, the Netherlands.

Oct. 29th – 30th, 2019

Development and teaching of a short course, titled *“Autodesk Revit 2019”*, at King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

Four-contact-hours course was taught for the Architectural Engineering students, which covered practical tasks and their solution procedures

Feb. 4, 2019

Development and teaching of a short course, titled *“Microsoft Excel: Applications of the Software in the Architectural Engineering Domain”*, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

A three-contact-hours course was taught for the Architectural Engineering undergraduate students, which covered concepts, techniques and practical exercises about the software uses in the domain of architectural engineering

July 2016 – Aug. 2016

Volunteer cost estimator, Arfa MS Society, Khobar, Saudi Arabia

Volunteered at Arfa Multiple Sclerosis “MS” Society from 30th July -11th August 2016, to prepare *an initial cost estimation study for a proposed renovation plan* of the society’s office in Khobar, Saudi Arabia

List of publications

Journal papers

Hamida, M.B., Remøy, H., Gruis, V. and van Laar, B. (2024). " Towards promoting circular building adaptability in adaptive reuse projects: A co-developed framework". *Smart and Sustainable Built Environment*, Ahead-of-print.

Hamida, M.B., Remøy, H., Gruis, V. and Jylhä, T. (2023). "Circular building adaptability in adaptive reuse: multiple case studies in the Netherlands". *Journal of Engineering, Design and Technology*, ahead-of-print.

Hamida, M. B., Jylha, T., Remøy, H., and Gruis, V. (2023). "Circular building adaptability and its determinants – A literature review", *International Journal of Building Pathology and Adaptation*, 41(6), 47-69.

Conference papers/presentations

Hamida, M.B., Greco, A., Remøy, H., Gruis, V. and van Laar, B. (2024). " Promoting circular building adaptability in an adaptive reuse project: An action- and design research-oriented experimentation". In *30th Annual Conference of the European Real Estate Society*, ERES: Conference. Sopot & Gdańsk, Poland.

Hamida, M.B., Remøy, H., Gruis, V. and van Laar, B. (2023). " Co-Development of a Framework for Circular Building Adaptability in Adaptive Reuse". In *Proceedings of the International Conference "Sustainable Built Environment and Urban Transition",* Linnaeus University, Växjö, Sweden.

Hamida, M.B., Jylha, T., Remøy, H., and Gruis, V. (2022). "Operationalising circularity and adaptability related real estate strategies: An exploratory study". In *28th Annual Conference of the European Real Estate Society*, ERES: Conference. Milan, Italy.

Book chapters

Hamida, M.B., Remøy, H., Greco, A., Gruis, V., and van Laar, B. (2025). “ Adapting for Tomorrow: Essential Prerequisites for Circular and Adaptable Design in Reuse Projects”. In *Research Companion on Circularity, Deconstruction, and Adaptability in Green Buildings,* (under review).

Hamida, M.B., and Gruis, V. (2024). “ Circulaire en aanpasbare gebouwtransformatie: Een overzicht van strategieën”. In *Transformatie naar Woningen,* 207-218, Delft University of Technology, Faculteit Bouwkunde, Delft, NL.

Media/blogs

Remøy, H., **Hamida, M.B**., and van Laar, B. (2024).”Circulaire transformatie: welke handvatten kunnen ingezet worden om circulaire transformatie haalbaar te maken?”, In *Service Magazine*, Faculty of the Built Environment, Eindhoven University of Technology.

Hamida, M.B., Remøy, H., and Gruis, V.. (2024). “ Towards a resource-efficient and future-proof built environment”. *Sustainable structures and infrastructures,* Emerald Publishing.

Video

Hamida, M.B., (2023). “Exploring the Relation Between Circularity and Adaptability in Adaptive Reuse”, In *Educators for Circularity*, Circular Built Environment (CBE) Hub, Faculty of Architecture and the Built Environment, Delft University of Technology.

25#15

Circular and Adaptable Building Transformation

Reconceptualization, Practice Exploration, Framework Co-Development and Implementation

Mohammad Basel Hamida

Existing buildings are changing assets, altered in response to various external or internal triggers for change. Often, change can occur in the form of adaptive reuse – also known as building transformation. Therefore, promoting adaptability in transformation is necessary to cope with the inevitability of building changes. Building transformation is considered an effective practice contributing to the circular economy (CE) and building adaptability as a prerequisite for circular design. However, previous research pointed out that building stakeholders lack knowledge about the alignment between CE and adaptive reuse.

This study aims to provide building and real estate practitioners with a guiding framework for promoting circularity and adaptability in adaptive reuse projects. A quadrant research design was used in this study to develop and apply the framework in practice. The four components of this research are four stepwise studies, namely theoretical – an integrative literature review, empirical – multiple case studies, participatory – framework co-development, and actionable – framework implementation.

First, the integrative literature review contributed to theoretically conceptualizing the underlying concept of this research – the circular building adaptability (CBA), which brings together circularity and adaptability. Second, the multiple case studies contributed to extracting lessons learned about applicable CBA strategies in adaptive reuse and their enabling and inhibiting factors. Third, the participatory study contributed to co-developing a descriptive framework for CBA in adaptive reuse (CBA-AR). Finally, the action research study contributed to testing and improving the usability and effectiveness of the CBA-AR framework based on observing, acting, and reflecting on a case project.

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