Practical guidelines towards a circular-adaptable reuse of vacant and obsolete real estate: A particular reference to the Dutch context.

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Abstract

The circular economy is an economic model in which resources are circulated in a closed loop by adopting the R-strategies (e.g. reuse, recycling and reduce) to minimize waste and pollution. Repurposing vacant buildings, which is known as adaptive reuse, is in line with the principle of circular economy, as it contributes to the reuse of the built assets instead of their demolition. In addition, this can help to conserve resources and reduce the environmental impact of building construction. Furthermore, adaptive reuse is not only necessary for vacant properties, but also for obsolete buildings. Thus, it is an unavoidable practice in the built environment. This implies that adaptability should be incorporated into this kind of projects besides circularity. However, recent research revealed that many of the Dutch adaptive reuse projects were implemented without an adequate consideration of circular solutions.

Accordingly, this research project aims to develop practical guidelines that could guide practitioners on how to operationalize circularity and adaptability in the adaptive reuse of vacant and obsolete real estate.

Sequentially, three approaches with different research methods were followed in order to answer the main research question: *''How can circularity and adaptability be promoted in the reuse of vacant and obsolete real estate?''*

The first approach is the documentation of existing knowledge. This approach was followed to answer the first sub-question: *''What are the criteria and measures for reusing obsolete and vacant buildings in a circular and adaptable manner?''* In this approach, a literature review was carried out. The literature review led to the identification of 12 criteria and 8 measures for circular and adaptable adaptive reuse.

The second approach is case studies on circular adaptive reuse projects of vacant and obsolete buildings. This approach was followed to answer the second sub-question: *''To what extent are circularity- and adaptability- related measures implemented in reusing vacant and obsolete buildings?''* In this approach, three research methods were used in two case studies, namely: archival research, interviews and field observation were used simultaneously. The findings of the cross-case analysis of two case studies resulted in adding 8 measures to the previously defined measures from the literature, totalling 16 measures.

The third approach is the formulation and validation of guidelines based on knowledge gained from theory and practice. This approach was followed to answer the third sub-question: ''*How can guidelines guide professionals on how to promote circularity and adaptability related measures in the reuse of vacant and obsolete buildings?'.'* In this approach, the guidelines were synthesized based on knowledge gained from the literature and findings of the two case studies. The results of developing and validating the guidelines contributed to adopting 13 guidelines. Overall, the outcomes of the validation indicate that the guidelines are informative and useful when they are visualized. However, they need to be updated constantly for their applicability in practice.

Keywords: Adaptive reuse, Adaptability, Circular Economy, Guidelines, Vacancy, Obsolescence, Real Estate, Circular building adaptability.

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1. Chapter 1: Introduction

1.1 Overview

This chapter includes the background, problem statement, aim and contribution of the research.

1.2 Background

In light of the resource scarcity and environmental degradation, the circular economy (CE) paradigm has been perceived as an effective sustainability paradigm for overcoming such kind of dilemmas (Askar *et al.*, 2022). This paradigm seeks out eliminating waste generation, eliminating the extraction of raw materials, and making use of waste as a resource through the principles of R-strategies (Hamida *et al.*, 2022). These strategies are numerous, including reuse, recycling, remanufacturing (Ghufran *et al.*, 2022). Many European Union (EU) nations has adopted the transition to this paradigm through different sectors (Cambier *et al.*, 2020).

Among those nations, the Netherlands launched in 2016 an ambition to the transition to CE. The ambition aims to transform all procedures, practices and industries from linear to circular (PBL, 2016). As the building industry plays a pivotal role in the energy consumption, material use and waste generation, the Dutch ambition motivates the adoption of circularity in the built environment (Rijksoverheid, 2016). Many circular practices have recently emerged in the Dutch building industry and property market. For instance, the rescue of building components and installation of renewable energy systems (Remøy and Van Der Voordt, 2007).

Adaptive reuse of buildings is one of the practices that are in line with the principles of CE, owing to its contribution to prolong and reuse the built assets (Munaro *et al.*, 2020). Furthermore, it is one of the useful means to cope with property vacancy and obsolescence. Which is proven by many office-housing transformation projects that were implemented in the Netherlands as a response to the economic recession that took place around 2008 (Wilkinson *et al.*, 2014).

1.3 Problem Statement

Obsolescence and vacancy are two interrelated issues that face the property market and the built environment worldwide (Remøy, 2014). Thus, and in this context, adaptive reuse and building adaptations are inevitable practices, owing to the occurrence of both issues beside different dynamics and contextual changes. For example, technological development, population growth and climate change. (Ross, 2017). In fact, the majority of the constructed buildings lack for adaptability, as they were constructed to meet the societal needs and requirements for a certain time without considering changes in the long term (Beadle *et al.*, 2008). Though adaptive reuse of buildings has been perceived as a practice that contribute to the transition to CE, however, not all of these projects are implemented in a circular manner. For example, Ikiz Kaya *et al.* (2021a) revealed that there is a limitation in considering the link between circularity and adaptive reuse in the Netherlands based on an exploratory study. Hamida *et al.* (2022) indicated that building adaptability should be aligned with circularity in the built environment to avoid overlooking contextual considerations in the built environment. These findings and arguments necessitate providing the stakeholders and practitioners with guiding tools for the circular and adaptable reuse of built assets that are less functioning. This means that such a guiding tool should be useable by a set group of professionals from the building industry and property market who participate in the design and redevelopment phases of adaptive reuse projects. These professionals usually comprise architects, engineers, contractors and building managers (Hamida and Hassanain, 2022). Building managers, in this research, are facilities managers and real estate managers, who are involved in the operation of the existing building (Bajaj *et al.*, 2011).

1.4 Research Aim

This research aims to develop practical guidelines that could guide practitioners on how to operationalize circularity and adaptability in the reuse of vacant and obsolete real estate.

1.5 Main Research Question

How can circularity and adaptability be promoted in the reuse of vacant and obsolete real estate?

1.6 Research Sub-Question

To answer the main research questions, the following sub-questions were be answered:

1. What are the criteria and measures for reusing obsolete and vacant building in a circular and adaptable manner?
2. To what extent are circularity- and adaptability- related measures implemented in reusing vacant and obsolete buildings?
3. How can guidelines guide professionals on how to promote circularity and adaptability related measures in the reuse of vacant and obsolete buildings?

1.7 Scientific and Societal Relevance of the Thesis

This thesis reflects scientific and societal relevance as follows:

1. This thesis expands the existing theory and knowledge on circularity and adaptability in adaptive reuse by providing further understanding of their practicality in the real practice.
2. This thesis provides professionals with practical guidelines that could guide them on applying circularity- and adaptability-related principles in adaptive reuse. With that, future adaptive reuse would be more circular, and thus, this will speed up the transition to CE.

1.8 Scope and limitations

Followings are the scope and limitation of this study:

- The field study was limited to the Dutch context .
- The case study was not limited to one building function, because this research seeks to tackle an ongoing problem that occurs in different buildings types using a newly emerged concept (circular building adaptability) that has been recently considered in the industry.
- Historic buildings are excluded in the case studies because of case-specific considerations pertaining to heritage, cultural and physical qualities/values of these buildings.

1.9 Research Structure

This thesis consists of 6 chapters, as follows :

1. *Introduction*: This chapter includes the background, problem statement, aim and contribution of the research.
2. *Conceptualized Model and Design of Research*: This chapter presents the conceptual model and the research design of this thesis.
3. *Literature Review*: This chapter comprises a review of the interconnected and relevant themes to this thesis , namely: building obsolescence and vacancy, adaptive reuse of buildings, circularity and adaptability in buildings, and practical guidelines.
4. *Case Studies*: This chapter briefly describes the explored cases and present the findings of within-case analysis and a cross-case analysis.
5. *Practical Guidelines for Circular and Adaptable Transformation of Vacant and Obsolete Buildings*: This chapter presents practical guidelines that are developed based on outcomes from the literature and case studies, and validated by professionals through structured interviews.
6. *Conclusions, recommendations and limitations*: This chapter concludes the thesis with the key concluding remarks, recommendations for researchers, practitioners and policy makers, and indication of the research limitations.

2. Chapter 2: Conceptualized Model and Design of Research

2.1 Overview
This chapter presents the conceptual model and the research design of this thesis.

2.2 Conceptual Model
This conceptual model is a problem-solution-oriented model that brings four interrelated problems with two interconnected solutions together in one context. In the problem side, the model considers tackling the dilemmas of building vacancy, building obsolescence, the slow movement towards the transition to CE and the lack of embodying adaptability in existing buildings.

In the solution side, the model perceives adaptive reuse as an effective solution for the building obsolescence, building vacancy and the need to speed the transition to CE. While practical guidelines for professionals are a solution for overcoming the slow movement towards the transition to CE and the lack of embodying adaptability in existing buildings. In summary, the model considers the development of practical guidelines for circular and adaptable reuse of vacant real estate as a central solution that brings the two solutions together to solve the four problems. Figure 1 shows the conceptual model of this research.

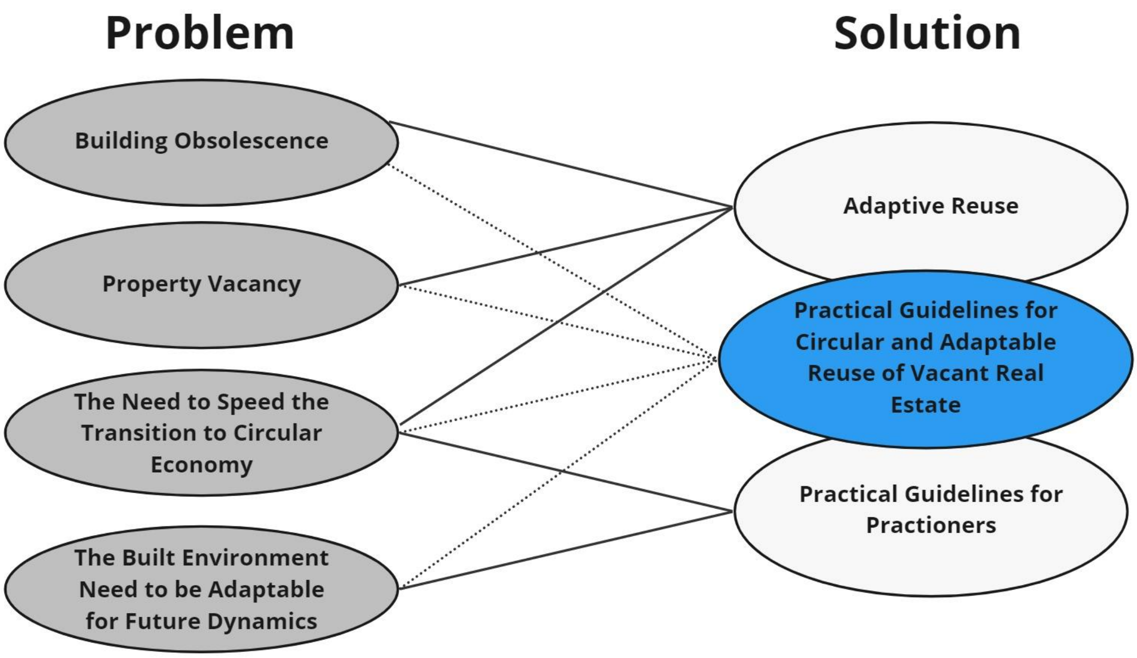

Figure 1: Conceptual model of the research (Source: own ill., 2023)

2.3 Research Design

Figure 2 presents the proposed research design. It coherently brings the research sub-questions, logic of inquiry, approach and methods together. With the three sub-questions in mind, this research design delivered three outcomes, namely:

1. Series of criteria and measures for building adaptability and circularity.
2. Documentation and comprehension of the extent in which circularity and adaptability related considerations are carried out in the reuse of vacant buildings.
3. Series of validated guidelines for circular and adaptable reuse of vacant buildings.

As shown in figure 2, different research methods were used in this research. By involving different research methods, triangulation of the research outcomes can be provided. In addition, it is a tactic for ensuring research credibility (Shenton, 2004).

2.3.1 Approach 1: Documentation of existing knowledge

This approach was followed to answer the first sub-question: *''What are the criteria and measures for reusing obsolete and vacant building in a circular and adaptable manner?''*
In this approach, the first research method was used which is the literature review.

Literature review is an important part of any research, as it provides researchers with an insight into what is already known. It is the foundation of every academic research (Xiao and Watson, 2019). The literature sources were obtained by searching in Google Scholar. The queries used are problem- and context- related and consists of four rounds;

1. Query 1: "circular" AND "adaptable" AND "building".
2. Query 2: "circularity" AND "adaptability" AND "building".
3. Query 3: "adaptive reuse" AND "circular" AND "obsolete".
4. Query 4: "adaptive reuse" AND "circular" AND "vacant".

Query 1 and 2 are more related to the concepts of adaptability and circularity. And query 3 and 4 are related to the context of the problem and solutions.

The documents that are reviewed include: books, journals, papers, reports, book chapters and conference papers. The selection of the documents is made according to the following criteria:

- Inclusion of aspects related to the circular redevelopments of the built environment, such as; renovation, retrofit and adaptation.
- Inclusion of features and characteristics of circularity and adaptability in buildings.
- Inclusion of criteria for circular and adaptable built environment.
- Inclusion of solutions, strategies and actions for circular and adaptable development of the built environment.

Research on circular cities and circular building materials was excluded.

Based on the knowledge to be obtained from the literature review, criteria and measures for adaptable and circular adaptive reuse were identified. In this research, criteria are descriptive and informative variables that define what circular and adaptable adaptive reuse would look like. Measures are the solutions and methods to that can be applied to meet these criteria.

2.3.2 Approach 2: Case studies on circular adaptive reuse projects of vacant and obsolete buildings

This approach was followed to answer the second sub-question: *''To what extent are circularity- and adaptability- related measures implemented in reusing vacant and obsolete buildings?''* In this approach, the case study used three research methods, namely: archival research, semi-structured interviews and field observation which were used simultaneously.

Case study starts with establishing theoretical propositions and rationale for the case, followed by defining the phenomenon of interests. The protocol of case study research should be critically and systemically developed and conducted, so it needs to be guided by a relevant research question (Yin, 2014). In this research, the phenomenon of interest is twofold: *what guidelines are followed for circular and adaptable adaptive reuse of vacant or obsolete buildings? And how these guidelines are used in the real practice context*? The inclusion of multiple cases is useful to gain a better understanding of the phenomenon of interests (Yin, 2009). Therefore, two case building projects were explored during the design phase, to get a better grasp and knowledge on the phenomenon of interest. In this research, the case is defined as a design project for adaptively reusing vacant or obsolete buildings. The alignment of each case with the conceptual model of the research were fulfilled. Accordingly, the followings are the 3-key criteria that were followed in selecting the cases of this research:

- **Operationalization of circular solutions**: Each project should demonstrate the operationalisation of circular solutions such as material reuse or recycling.
- **Operationalization of solutions for building adaptability**: Each project should demonstrate the inclusion of adaptable design means, such as the use of demountable building products and flexible building configuration.
- **The adaptive reuse should be carried out to tackle the problem of building obsolescence and/or vacancy**: The adaptive reuse of historic buildings was excluded. Because of case-specific considerations pertaining to heritage, cultural and physical qualities/values of these buildings.

The archival material in this part is data on the project from the design team such as drawings and specifications, also non-project related data such as guidelines or regulations.
Archival research is an exploratory method for exploring documents prepared by organizations (Ventresca and Mohr, 2002). In this research, existing documents containing guidelines on circular design tools and measurement criteria were reviewed. The documents include materials produced by public and private institutions.
Then, documents on the building design and specifications were reviewed to build a profile on the projects. Lastly, the used policy documents and guidelines for circular and adaptable design by the project team were reviewed.

The observation in the field took place by attending different project activities, including meetings and construction-processes. In field observation, the researcher seeked out documenting the guidelines or guiding tools that professionals use to design for circular and adaptable adaptive reuse, also understanding the way in which these guidelines or tools are being used. In this study, observation and documentation of the way in which guidelines for circular and adaptable design is used were carried out. To document the observations, notes and photographs were taken.

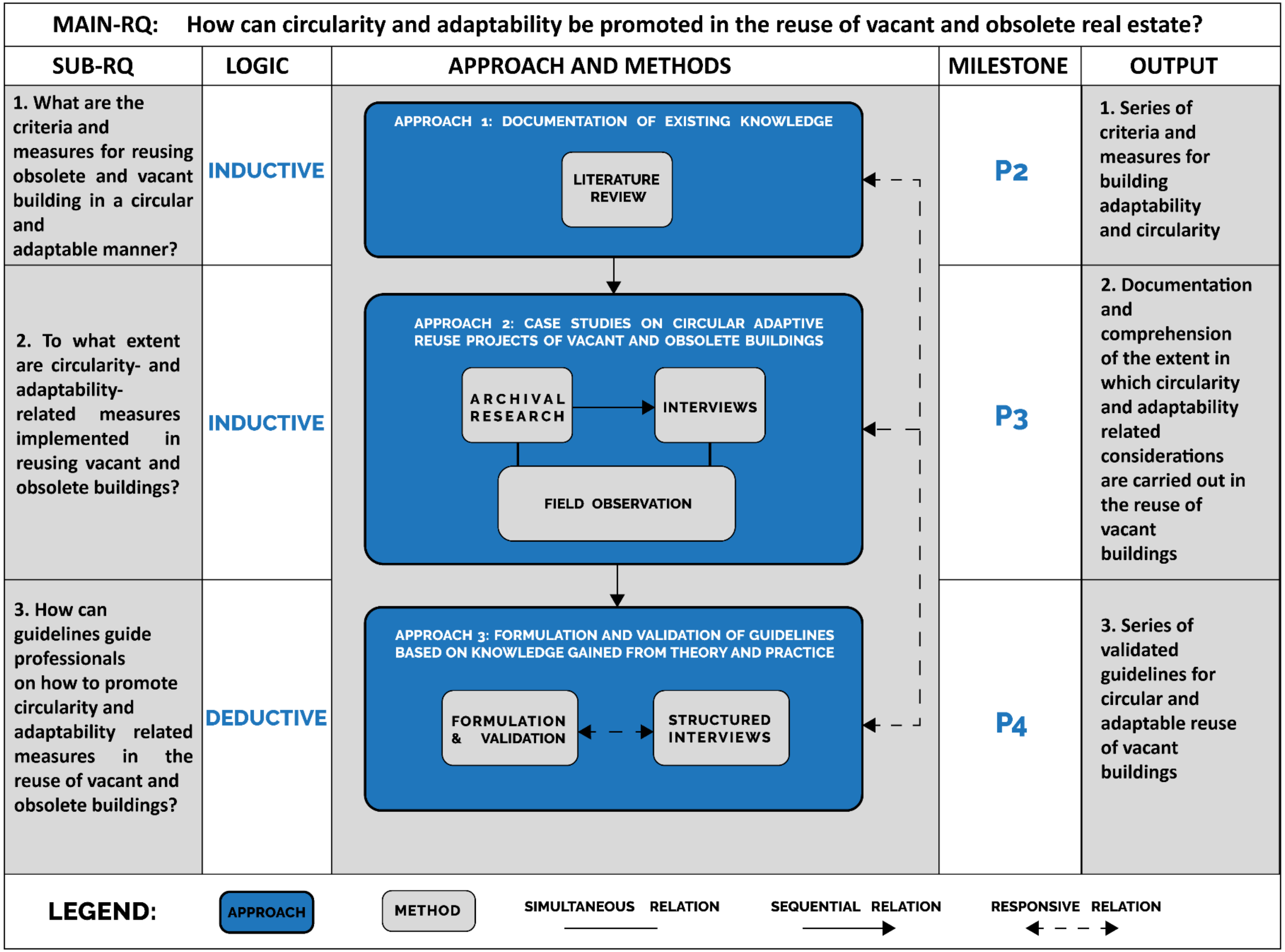

Figure 2: Research design (Source: own ill., 2023)

The design of the interview protocol (see Appendix A) was inspired on the method of Hennink *et al.* (2011). In an individual in-depth interview, interviewer interviews an interviewee to ask a series of open ended questions that are included in the interview guide. From each project, at least three participants were interviewed. Table 1 provides a profile of the conducted interviews. For more information about the interviewees, see table 1.

Table 1: Profile of the conducted semi-structured interviews in each case study.

Case study:	Interviewee:	Role during the project redevelopment:	Type of interview:	Date – Duration:
Case study 1	Interviewee A	Developer at development firm that redeveloped the building	Online	April 26th , 2023 – 1:30:27
	Interviewee B	Developer at development firm that redeveloped the building	Online	May 10th , 2023 – 46:38
	Interviewee C	Director at development firm that redeveloped the building	Phone call	Nov. 8th , 2023 – 23:11
Case study 2	Interviewee D	Consultant at project management firm that redeveloped the 3 towers	Online	Aug. 25th , 2023 – 1:15:08
	Interviewee E	Director at development firm that redeveloped the 7 towers	Phone call	Oct. 31st , 2023 – 22:40
	Interviewee F	Director of the school that is operating the 3 towers	Online	Nov. 7th , 2023 – 1:01:08
	Interviewee G	Consultant in design team that redeveloped the 3 towers	Online	Nov. 16th , 2023 – 26:46

The interviews were used for two purposes in the case study:
- Explore the guidelines that are followed in practice.
- Comprehend the way in which these guidelines are used.

2.3.3 Approach 3: Formulation and validation of guidelines based on knowledge gained from theory and practice

This approach answered the third sub-question: ''*How can guidelines guide professionals on how to promote circularity and adaptability related measures in the reuse of vacant and obsolete buildings?*''

In this approach, the guidelines were synthesized based on knowledge gained from the literature and archival research as well as findings of the case study. An iterative process was followed in the development and validation of the guidelines.

First, the guidelines for circular and adaptable reuse of vacant and obsolete real estate were formulated based on knowledge gained from approach 1 and approach 2. The guidelines provided a series of advising statements on what should building practitioners – including designers, contractors and building managers – consider and conduct to adaptively reuse these properties in a circular and adaptable manner.

Second, four structured interviews were carried out to validate the guidelines. In these interviews, the formulated guidelines were discussed with relevant professionals from the Dutch building industry/property market as shown in table 2. To involve expert interviewees, two practitioners who have previous experience in fostering circularity and adaptability in transforming vacant or obsolete real estate were interviewed. These interviewees were selected and contacted based on their previous contribution to the case study or experience in the research context. In each interview, the formulated guidelines were presented to the interviewees per their sequence and categories. The interviewees were asked to give their feedback on the clarity and adequacy of the guidelines. For the analysis, the documented observations and feedback were reported and discussed with two researchers as a secondary source for data triangulation.

Table 2: Profile of the conducted structured interviews in validation of guidelines.

Guideline Validation:	Interviewee:	Role during the project redevelopment:	Type of interview:	Date – Duration:
	Interviewee D	Consultant at project management firm that redeveloped the 3 towers	Online	Dec. 8th , 2023 – 47:34
	Interviewee F	Director of the school that is operating the 3 towers	Online	Dec. 11th , 2023 – 43:38
	Interviewee A	Developer at development firm that redeveloped the building	Online	Dec. 14th , 2023 – 41:44
	Interviewee D	Consultant at project management firm that redeveloped the 3 towers	Online	Jan. 9th , 2024 – 49:30

3. Chapter 3: Literature review

3.1 Overview

This chapter addresses the first sub-question of what are the criteria and measures for reusing obsolete and vacant building in a circular and adaptable manner. Therefore, it comprises a review of the interconnected and relevant themes to this thesis, namely: building obsolescence and vacancy, adaptive reuse of buildings, circularity and adaptability in buildings, and practical guidelines. See section 2.3.1 for more information on this research approach.

3.2 Building Obsolescence and Vacancy

Building obsolescence and vacancy are amongst the common dilemmas that occur in the built environment. Following is a description of both concepts.

3.2.1 Building Obsolescence

Building obsolescence is the decline in the performance of the building , leading to the end of the service life of the built asset (Thomsen and Van Der Flier, 2011). Building obsolescence can be manifested in 10 ways as follows (Remøy, 2014):

1. Aesthetic obsolescence: when the building losses its aesthetic attraction.
2. Functional obsolescence: occurs for instance when the users way of working changes.
3. Legal obsolescence: resulting from new legal regulations (Langston *et al.,* 2008).
4. Social obsolescence: when the building does not reflect the users image anymore.
5. Tenure obsolescence: is the disagreement between owner and user of the building.
6. Structural obsolescence: deterioration of the supporting structure.
7. Financial obsolescence: mismatch between costs and yield (Baum and Hartzell 1997).
8. Environmental obsolescence: the result of environmental changes.
9. Locational obsolescence: the effect of functional obsolescence and image issues of the location
10. Site obsolescence: mismatch between site value and building value.

3.2.2 Building Vacancy

A vacant building can be described as a built-asset that has become underutilized, unoccupied, or empty for a period of time (Insuranceopedia, 2018). Vacancy can take place due to market dynamics or even when the building itself becomes obsolete (Wilkinson *et al.*, 2014). Generally, there are different types of building vacancy, such as:

- Structural Vacancy: is defined as emptiness of unit area within the building for three years or more (Remøy, 2010).
- Natural Vacancy: also known as 'healthy' which ranges between 3% to 10%, and it occurs usually when there is balance in the trends of supply and demand trends (Armstrong *et al.*, 2021).

This research considers the structural vacancy, as it is the problematic condition that could result from market dynamics.

3.3 Adaptive Reuse of Buildings

Adaptive reuse in the built environment refers to reusing an existing property for another goal than it was originally designed for (Caves, 2005). It is a coping strategy to handle building vacancy and obsolescence (Remøy, 2010).

3.3.1 Adaptive Reuse Definition

Adaptive reuse – also known as conversion, across-use adaption or building transformation – is a type of building adaption that seek out refunctioning the use of a building (Shahi et al., 2020; Wilkinson et al., 2014). Numerous definitions were formulated to define adaptive reuse. One of the oldest definitions was defined as *"Conversion of a facility or part of a facility to a use significantly different from that for which it was originally designed."* (Iselin and Lemer, 1993).

3.3.2 Benefits of Adaptive Reuse

Adaptive reuse can reflect numerous sustainable benefits. From a financial point of view, it can reduce the cost of building new structure by adapting an existing building that is suitable for the considered use (Armstrong *et al.*, 2021). Environmentally , adaptive reuse contribute to the mitigation of climate change and resource scarcity, by reusing the existing assets and prolong their use (Langston & Conejos, 2014). Finally, from a social sustainability point of view, adaptive reuse is a strategy to preserve the monumental buildings and revitalize them (Cerreta *et al.*, 2020).

Recently, adaptive reuse, has been considered as an effective practice for the transition to CE, owing to its alignment with the principle of the R-strategies (Foster, 2020).

3.4 Circularity and Adaptability in Buildings

Circular economy is a sustainability paradigm that seeks out eliminating waste generation, and environmental impact closing the resource loops – also called the value chain, by adopting and applying R-strategies related solutions and processes (Kirchherr *et al.*, 2017). Further, circularity seeks out adding value to existing resources and prolong their use, by keeping them at their highest utility and value (Ellen Macarthur Foundation, 2022). In a circular economy, almost all products are reprocessed by one of the R-strategies such as reuse and recycling. If a product is broken, it can be repaired as a strategy to prolong its usefulness (ARUP, 2016).

3.4.1 The Circular Economy in the Built Environment

As the built environment is a major contributor to resource consumption and waste generation, the adoption of CE in the building industry has been perceived as a crucial step (ARUP and Ellen MacArthur Foundation, 2018).

3.4.1.1 Models and Frameworks for CE

Different models for CE were constructed. The butterfly Diagram and ReSOLVE are amongst the key models for CE. The first is more conceptual, while the second is more industry oriented.

A. Butterfly Diagram

The butterfly diagram model in figure 3 seeks out keeping products, materials and components in use at their highest value within the cyclable chain at all times. Ultimately it attempts to decouple economic growth and development of waste and environmental impact rooted in CE, by distinguishing between two types of cycles, namely technical and biological cycles. (Ellen Macarthur Foundation, 2022)

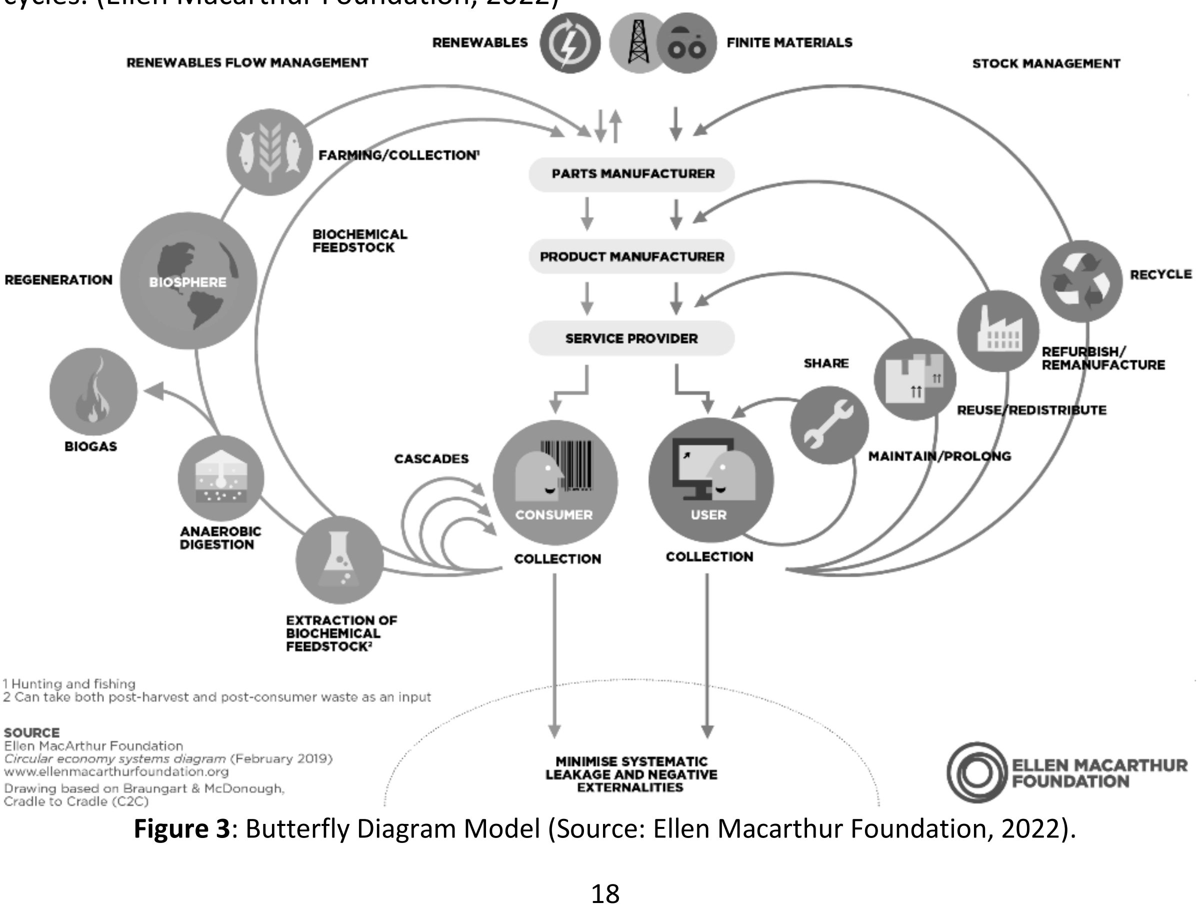

Figure 3: Butterfly Diagram Model (Source: Ellen Macarthur Foundation, 2022).

First, in the technical cycles, products, components and materials are kept in circulation in the economy for as long as possible. Technical cycles are usually for products made from non-biodegradable materials such as metals. The most effective technical cycles involve maintaining products or applying one the R-strategies on them. Thereby, the value of a product is preserved and its usage is increased or efficiently re-processed. The R-strategies included in the technical cycle are reuse, redistribute, recycle, refurbish and remanufacture (Ellen Macarthur Foundation, 2022).

Second, in the biological cycles, natural resources are turned back to nature. Biodegradable materials include food or wood based products that are renewable or can be reprocessed in nature. Different strategies are utilized in the biological cycles for the different types of materials. For instance, organic materials that cannot be used further can be composted or anaerobically digested to extract valuable nutrients. The strategies used for operating the biological cycles can minimize the systematic leakages and negative externalities (Ellen Macarthur Foundation, 2022).

B. ReSOLVE

The ReSOLVE principle explains how to decouple resource use from growth in industry. The framework contains six action areas for businesses namely; Regenerate, Share, Optimise, Loop, Virtualise and Exchange as shown in figure 4.

Figure 4: ReSOLVE framework showing the core principles of circularity applied to six actions (Source: Gower, 2016)

In fact, ReSOLVE starts with the letters ''Re'', as it considers the use of renewable resources from wind, solar and recycling our waste. Furthermore, regenerating natural capital, repairing and refurbishing or recycling and reusing our products and goods are incorporated in ReSOLVE. The ReSOLVE also comprises the concept of sharing resources as a mean to increase the efficiency of using existing resources. Finally, the last 3 elements seek out closing the material loop by tracking the resource use, using digital technologies instead of physical resources, and exchanging resources with energy-efficient alternatives. (Gower, 2016)

3.4.1.2 Models and Frameworks for Circular Built Environment

a. Resource-efficient built environment

Ness and Xing (2017) designed a conceptual model for a resource efficient built environment, with the aim of facilitating synergistic and integrated solutions. Figure 5 illustrates the conceptualized model for resource-efficient built environment.

The model consists of 8 central components, namely; ''a closed-loop process for the life cycle of built environments; networks of actors; resources and instruments as the key elements of the urban system; synergies among these key elements; strategies for identifying and managing synergies; and, at its core, desired outputs of a resource-efficient built environment'' (Ness and Xing, 2017). The model highlights the importance of bringing different processes, networks and measures together in an aligned way.

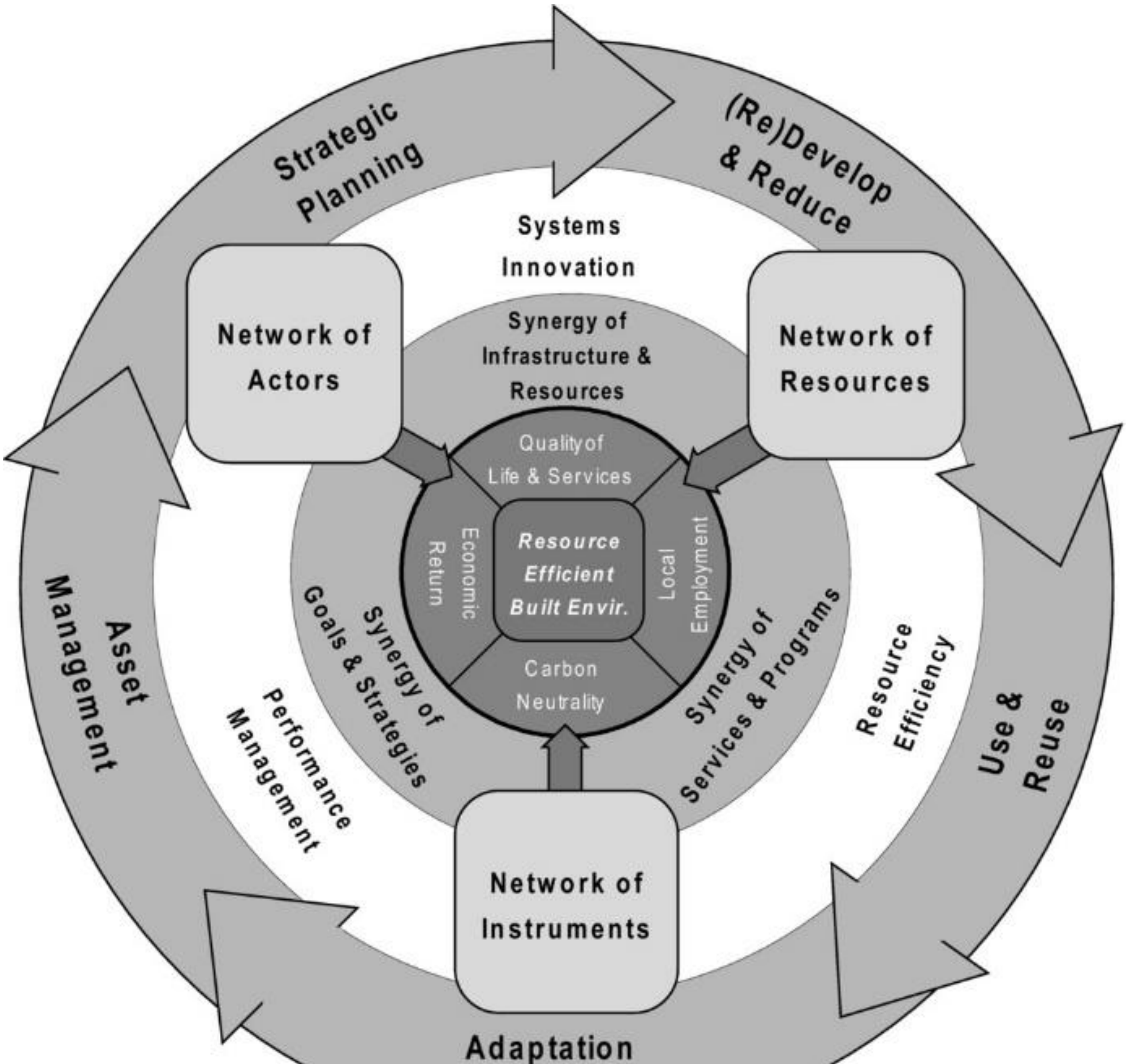

Figure 5: A Conceptual model for resource-efficient built environment (Source: Ness and Xing, 2017).

3.4.2 Adaptability in Buildings

Building adaptability has numerous definitions. Overall, most of the definitions express it as the capacity of a building to facilitate future changes (Pinder *et al.*, 2017). Adaptability is important building feature, as all existing buildings undergo changes due to building-related and non-building related causes (Kamara *et al.,* 2020). Moreover, building adaptability is one of the keys for applying CE in buildings, because it facilitates keeping or returning back the building material in the loop – also called the value chain (R. J. Geldermans, 2016).

3.4.2.1 Models for Building Adaptability

The shearing layer concept was synthesized by Steward Brand (1994). The concept perceives that building changes take place in different layers and in different periods of time shown figure 6.

The shearing layer model considers that the interior layers are changeable often, and thus, they should be flexible. In this context, the model considers that external building layers are long-lasting, and thus, they should be durable. The model divides the building layers into 6 categories with different lifespans, as shown in table 3.

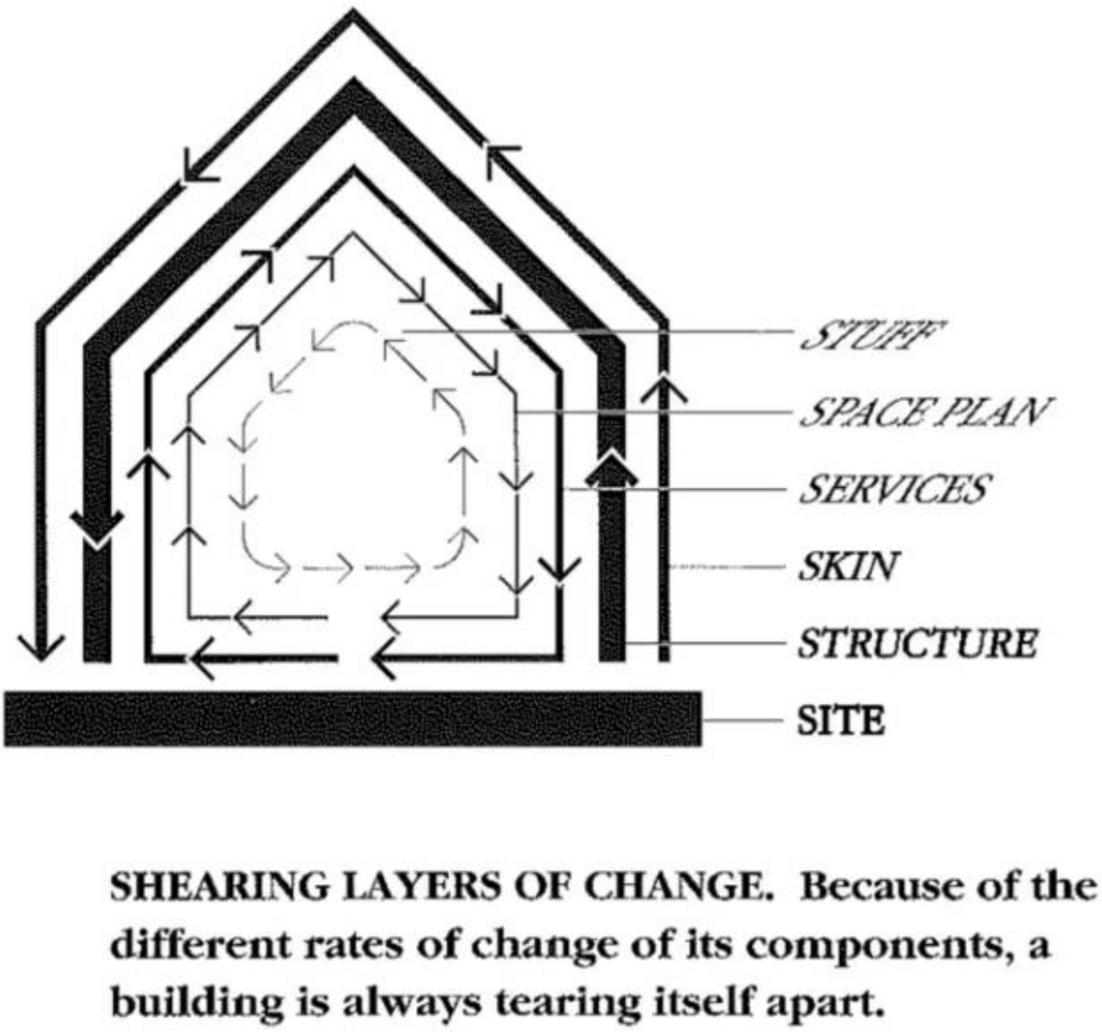

Figure 6: The shearing layers concept (Source: Brand, 1994).

Table 3: Description and lifespan of the shearing layers components.

Layer	Brief description	Lifespan (years)
Site	The site is infinite. This layer contains spatial, climatic, social, cultural and economic aspects.	∞
Structure	Foundation of the building, load bearing elements. This layer has high cost to change.	30-300
Skin	The façade and the roof. Can also be part of the structure, in that case harder to change.	20
Services	Wires, elevators, heating/ventilation systems, fire safety systems and so on. Easy to change however sometimes too integrated with the building, if so, could lead to early demolishment of the building.	7-15
Space plan	Interior layout like doors, walls and floors. If market is highly dynamic this layer changes every three years. In other markets it can last thirty years.	3-30
Stuff	Lamps, chairs and desks for instance. Needs change sometimes daily or monthly.	<1

Source: Adapted from (Brand, 1994)

3.4.3 Operationalizing Circularity and Adaptability in Buildings: The Circular Building Adaptability Concept and its Determinants

The integration and alignment between building circularity and adaptability is important to eliminate waste and keep the functionality of the buildings in the long term (Hamida et al., 2022).

Hamida *et al*. (2022) redefined circularity and adaptability with a new capitalization, so-called 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''.* CBA can be realized through 10 design and operation determinants; configuration flexibility, product dismantlability, asset multi-usability, design regularity, functional convertibility, material reversibility, building maintainability, resource recovery, volume scalability and asset refit-ability. These determinants comprise configuration-, use- and operation-oriented solutions. Following is a brief description of these determinants (Hamida et al., 2022)

1. *Configuration flexibility; also known as adjustability.* Which is the most famous determinant and shows the possibility of a building to cope with change through light adjustments that do not cost much time such as movable building components.
2. *Product dismantlability; or removability.* This determinant is about the ability of building parts to be easily removed and is interrelated with movability.
3. *Asset multi-usability; or versatility*. The multifunctional use of spaces and areas without major change, like multi-purpose space and smart control systems.
4. *Design regularity; or modularity.* Designing prefabricated building components on spatial level and physical level of the building.
5. *Functional convertibility; or transformability.* This one is more context-specific and relates to the building's ability to house a new function with respect to physical, legal, economic boundaries, architectural, cultural and locational aspects. It is interrelated

with multifunctionality of building area's and spaces, however, it is more about the building as a whole.

6. *Material reversibility; also called movability and relocate-ability.* Changing location of the asset or components easily. It can be embedded by making use of demountable, independent or relocatable systems. This determinant is part of configuration flexibility, because it considers changeability.
7. *Building maintainability; or availability.* Accessing building components and systems for further operation. Achieved by technical spaces, dismountable products and interaction between technical systems.
8. *Resource recovery; known as recyclability and reusability.* Determines to what extent materials can be reused or recycled. For example by making use of discrete products, standardised building components building products as a service.
9. *Volume scalability; also called elasticity.* The possibility of the building to change its scale or volume vertically or horizontally and its ability to merge or separate spaces.
10. *Asset refit-ability;* components and systems that allow for manipulation and improvement. This can be done with dismountable products, interaction of systems and surplus capacity in the building design. Furthermore, this determinant is interrelated with building maintainability because both adjust technical performance. (Hamida et al., 2022)

3.4.4 Criteria for Circular and Adaptable Adaptive Reuse of Buildings

The reviewed literature contributed to a preliminary definition of criteria and measures for circular and adaptable adaptive reuse. Based on the adopted selection criteria, papers that cover various aspects of circular and adaptable building were reviewed. The identified criteria and measures were listed in two tables. Table 4 lists the most frequent criteria in the reviewed papers. Table 5 lists the most frequent measures in the reviewed papers. These tables provide a useful overview of the most commonly discussed criteria and measures that were useful for a circular and adaptable adaptive reuse in the current literature, so they can be used as a guide for the practical guidelines besides the knowledge to be gained from the case studies.

3.4.4.1 Design for Disassembly (DfD)

The concept of DfD can be described as the ease of disassembling and reusing product components (Antonini et al., 2020 ; Askar et al., 2021 ; Dams et al., 2021 ;). DfD is crucial to the circular adaptation of buildings because it facilitates the reuse of the disassembled products without causing any damage or waste (Askar et al., 2022 ; Bertino et al., 2021 ; Eliote and Leite, 2022 ; Geldermans, 2016 ; Hamida et al., 2022 ;). DfD can be fulfilled by using dry connections instead of wet connections (Dams et al., 2021 ; Geldermans et al., 2019 ; Iyer-Raniga, 2019), and installing of dismantlable products (Rahla et.al 2021b). The principles of design for disassembly are fundamental to the realization of a more circular and sustainable built environment (ARUP and Ellen MacArthur Foundation, 2020).

Table 4: Criteria for circular and adaptable adaptive reuse of building.

	Design for Disassembly: The ease of demounting building products	**Material Efficiency:** The capacity to optimize the use of material resources and minimize waste generation	**Energy Efficiency:** The capacity to reduce the use of energy in buildings	**Reusability:** The capacity to reuse building materials and components beyond their lifespan	**Durability:** The capacity to promote the robustness and longevity of building materials and components	**Flexibility:** The capacity to promote the versatility of a buildings design and reconfiguration of its layout	**Functional Convertibility:** The capacity to repurpose the building function	**Technological Refit-Ability:** The capacity of a building to incorporate new and evolving technologies	**Ecological Resilience:** The capacity of a building to withstand and mitigate environmental changes	**Social and Cultural Acceptability:** The building capacity to satisfy social and cultural needs	**Biodegradability:** The capacity to decompose a physical object naturally into constituent elements at the end of its useful life, without causing harm to the environment	**Energy Renewability:** The capacity to promote the energy renewability in buildings
(Akhimien et al., 2021)	X	X		X		X				X		
(Antwi-Afari et al., 2022)	X	X	X	X	X	X	X					X
(Andersen et al., 2022)		X		X								
(Askar et al., 2021)	X	X		X	X		X	X	X			X
(Askar et al., 2022)	X	X	X	X	X	X	X	X		X		
(Bertino et al., 2021)	X	X	X	X								
(Dams et al., 2021)	X			X	X						X	
(Dewagoda et al., 2022)	X	X		X		X		X		X		
(Eberhardt et al, 2022)	X	X	X	X	X	X	X					
(Eliote and Leite, 2022)	X			X	X	X				X		
(Foster, 2020)			X	X				X	X	X	X	
(Geldermans 2016)	X	X		X		X	X			X		
(Geldermans et al., 2019)	X			X		X	X			X		X
(Girard, 2020)		X	X	X				X	X	X		X
(Hamida et al., 2022)	X	X	X	X		X						X
(Hamida et al., 2023)	X	X	X	X		X						X

(Ikiz Kaya et al., 2021a)			X	X		X	X			X		
(Ikiz Kaya et al., 2021b)			X	X						X		
(Iyer-Raniga, 2019)	X	X	X	X	X	X		X	X	X		X
(Kanters, 2020)	X	X		X		X		X		X		X
(Khadim et al., 2022)	X	X	X	X		X				X	X	X
(Owojori et al., 2021)		X	X	X		X		X		X		
(Owojori and Okoro, 2022)		X	X	X				X	X	X		X
(Rahla et al., 2021a)	X	X	X	X	X	X		X		X	X	X
(Rahla et al., 2021b)	X	X	X	X	X	X		X	X	X	X	X
(Sanchez & Haas, 2018)	X		X	X	X			X	X	X		
(Scolaro and De Medici, 2021)		X	X	X	X	X		X	X	X		
(Sedova, 2022)				X			X			X		
(Stijn and Gruis 2020)	X	X	X	X				X			X	X
(Webb et al., 1997)	X	X	X	X	X	X						
(Xing et al., 2020)	X	X	X	X	X	X	X	X				X
Frequency	22	23	21	31	13	19	9	15	8	20	6	14

Table 5: Measures for circular and adaptable adaptive reuse of buildings.

	Use Material Passports (MP): Documentation of characteristics and performance of building materials	**Use Recycled Materials:** The use of recycled materials in building applications	**Use Dismantlable Design**: The use of demountable products	**Use Unitized Design:** Modularization and standardization of the building design	**Use Digital Technologies:** The utilization of the digital technologies in the building design and operation	**Use Regenerative Design Principles:** The adoption of solutions that promote renewability of resources in buildings	**Share Resources:** The promotion of multiplicity of the use of resources in buildings	**Leasing Resources (Products as a service):** A procurement strategy where the facade builder oversees the entire lifecycle of the building envelope
(Akhimien et al., 2021)								
(Antwi-Afari et al., 2022)	X	X	X	X	X			
(Andersen et al., 2022)		X						
(Askar et al., 2021)	X	X	X	X	X	X	X	
(Askar et al., 2022)	X	X	X		X	X		
(Bertino et al., 2021)	X	X	X	X	X			
(Dams et al., 2021)		X	X	X	X	X		
(Dewagoda et al., 2022)	X	X	X	X	X	X	X	
(Eberhardt et al, 2022)		X	X	X		X	X	
(Eliote and Leite, 2022)		X	X	X	X	X		
(Foster, 2020)	X	X				X	X	
(Geldermans 2016)		X	X		X	X		
(Geldermans et al., 2019)	X	X	X	X		X		
(Girard, 2020)		X			X	X	X	
(Hamida et al., 2022)	X	X	X	X	X	X	X	
(Hamida et al., 2023)	X	X	X	X	X	X	X	X
(Ikiz Kaya et al., 2021a)						X	X	
(Ikiz Kaya et al., 2021b)		X				X		
(Iyer-Raniga, 2019)	X	X	X	X	X	X	X	X
(Kanters, 2020)	X	X	X		X			
(Khadim et al., 2022)	X	X	X		X	X		
(Owojori et al., 2021)		X				X	X	
(Owojori and Okoro, 2022)		X						
(Rahla et al., 2021a)	X	X	X	X	X	X	X	
(Rahla et al., 2021b)	X	X	X			X	X	
(Sanchez & Haas, 2018)		X	X			X		

(Scolaro & De Medici, 2021)		X		X		X		
(Sedova, 2022)							X	
(Stijn and Gruis 2020)		X	X	X		X	X	
(Webb et al., 1997)		X	X	X				X
(Xing et al., 2020)	X	X	X		X		X	X
Frequency	15	28	21	15	16	22	15	4

3.4.4.2 Material Efficiency

Material efficiency is a fundamental design principle that considers minimizing waste and optimizing the utilization of resources by constructing buildings and producing with the minimum amount of required materials (Ruuska and Häkkinen, 2014). In the context of adaptive reuse, the concept of material efficiency is a crucial factor for resource conservation (Akadiri et al., 2012). Furthermore, material efficiency in circular adaptation of buildings can assist in reducing the carbon footprint of buildings by diminishing the amount of energy and resources used in construction, operation, and dismantling (Iyer-Raniga, 2019 ; Kitagorsky, 2022). To accomplish material efficiency in buildings, designers can adopt an array of strategies, including constructing buildings with reduced environmental footprints (Wilkinson et al., 2014) or employing prefabrication (Minunno et al., 2018). Applying material passports (MPs) is an effective strategy for promoting material efficiency (Akhimien et al., 2021). By promoting material efficiency, designers can develop buildings that are suited to a circular economy (ARUP and Ellen MacArthur Foundation, 2020; Bertino et al., 2021 ; Kanters, 2020 ; Khadim et al., 2022).

3.4.4.3 Energy Efficiency

Energy efficiency is a fundamental design principle that concentrates on reducing the amount of energy use in buildings (Harputlugil and de Wilde, 2021). In the context of circular adaptation of buildings, energy efficiency is an indispensable consideration, as it can substantially contribute to attaining energy neutrality (Foster, 2020). To achieve energy efficiency in building design, designers can use life cycle assessment (LCA) to evaluate and compute decisions on the environmental impact and energy efficiency of for instance different building façades (Antwi-Afari et al., 2022). Achieving energy efficiency is an essential step in developing a circular built environment, as it facilitates coping with resource scarcity (ARUP and Ellen MacArthur Foundation, 2020 ; Iyer-Raniga, 2019).

3.4.4.4 Reusability

Reusability is a design principle that considers the continued use of building materials and components beyond their lifespan (Minunno et al., 2018). In the context of circular adaptation of buildings, reusability is a crucial aspect since it can help minimize waste and extend the useful life of building materials and components (Askar et al., 2022; Bertino et al., 2021 ; Eliote and Leite, 2022). To accomplish reusability in building design, designers can use a variety of techniques such as designing for flexibility and adaptability (Rahla et al., 2021a) and integrating deconstruction into the building's lifecycle (Iyer-Raniga, 2019).

3.4.4.5 Durability

Durability in buildings is a design principle that emphasizes the robustness and longevity of building materials and components (Antonini et al., 2020 ; Askar et al., 2021 ; Eliote and Leite, 2022) In the context of circular adaptation of buildings, durability is a crucial factor that can help to prolong the life of buildings and their components (Askar et al., 2022) and reduce the need for replacements (Minunno et al., 2018). To achieve durability in building design, designers can use various strategies such as selecting materials with high durability and low maintenance needs (Dams et al., 2021). The principles of durability are essential to realize a circular built environment (ARUP and Ellen MacArthur Foundation, 2020 ; Iyer-Raniga, 2019 ; Rahla et al., 2021a ; Rahla et al., 2021b).

3.4.4.6 Flexibility
Flexibility in buildings refers to the capacity to promote versatility of a building's design and reconfigure its layout (Askar et al., 2021 ; Geldermans et al., 2019). Within the framework of circular adaptation of buildings, flexibility is a significant consideration since it can prolong the useful life of a building and adapt to changing needs and uses over time (Askar et al., 2022 ; Geldermans, 2016). Designers can use a variety of approaches to achieve flexibility in building design, such as open floor plans and adaptable building systems (Geldermans et al., 2019). The principles of flexibility are essential for achieving a circular built environment (ARUP and Ellen MacArthur Foundation, 2020 ; Hamida et al., 2022 ; Iyer-Raniga, 2019 ; Kanters, 2020 ; Rahla et al., 2021a).

3.4.4.7 Functional Convertibility
Functional convertibility is a design principle that emphasizes a building's ability to adapt to new and changing functional requirements over its life cycle (Hamida et al., 2022). In the context of adaptive reuse and circularity, functional convertibility is a critical consideration as it can help prolong the useful life of a building (Askar et al., 2022) by enabling it to adjust to changing user needs and functions (Ikiz Kaya et al., 2021a). Designers can achieve functional convertibility in building design by employing various strategies, such as, integrating flexible systems (Askar et al., 2021) or designers should prioritize connections and dimensions as leading principles, integrating cut-outs for future functions to achieve adaptability (Geldermans, 2016).

3.4.4.8 Technological Refit-Ability
Technological refit-ability is a design principle that emphasizes a building's capability to incorporate new and evolving technologies throughout its lifespan (Hamida et al., 2022). In the context of circular adaptation of buildings, the ability to provide new technologies is a significant consideration as it can extend the useful life of a building by allowing it to integrate new technologies and remain relevant over time (Foster, 2020). To achieve technological refit-ability in building design, designers can employ a variety of strategies, including the use of technologies that allow or facilitate a specific action or process (Antonini et al., 2020).

3.4.4.9 Ecological Resilience
In the built environment, ecological resilience refers to the capacity to adapt to changes, instead of resisting them (Garcia, 2022). Wilkinson et al., (2014) indicated that sustainable construction is the process of establishing a sound and healthful built environment through the implementation of resource-efficient and ecologically-based principles. Resilience in building adaptation needs to mitigate deterioration which is a crucial factor in extending the useful life of a building by enabling it to react to changing environmental conditions (Askar et al., 2021 ; Girard, 2020).

3.4.4.10 Social and Cultural Acceptability
Social acceptability is a design principle that highlights a building's capacity to fulfil several elements like community involvement and empowerment through social participation and/or improvement of life quality (Owojori and Okoro, 2022). Cultural acceptability is a design principle that highlights education and consciousness-raising among community members regarding the environment and/or conservation of cultural legacy (Owojori and Okoro, 2022).

In the context of circular adaptation of buildings, social/cultural aspects are key factors for extending the building's useful life (Askar et al., 2022). To meet the requirements of social/cultural acceptability in building design, designers can utilize various approaches such as engaging with local communities to comprehend their preferences and requirements (Foster, 2020) and integrating cultural features into the building's design (Ikiz Kaya et al., 2021a).

3.4.4.11 Biodegradability

Biodegradability can be describes as the capacity to decompose a physical object naturally into constituent elements at the end of its useful life, without causing harm to the environment (Rahla et al., 2021b). In the context of circular adaptation of buildings, biodegradability is a crucial aspect as it can help minimize the environmental impact of building materials and reduce waste (Foster, 2020 ; Rahla et al., 2021a). Designers can implement various strategies to achieve biodegradability in building design, such as providing green roofs or living walls that help to reduce the need for mechanical cooling (Calheiros and Stefanakis, 2021). The principles of biodegradability are fundamental in achieving a circular built environment (Dams et al., 2021 ; Khadim et al., 2022).

3.4.4.12 Energy Renewability

The principle of renewable energy is the use of energy derived from sources that are naturally renewed (Geldermans et al., 2019 ; Hamida et al., 2022). In the context of circular adaptation of buildings, the use of renewable energy sources is of utmost importance as it aids in reducing greenhouse gas emissions, creating waste-free designs and closed-loop systems (Rahla et al., 2021a). Several strategies can be used by designers to achieve renewable energy sources in building design, such as flexible heating and cooling (Foster, 2020).

3.4.5 Measures for Circular and Adaptable Adaptive Reuse of Buildings

3.4.5.1 Use Material Passports

The use of material passports (MP’s) is a record of detailed data such as dimensions, material type and shape to enable efficient supply chain collaboration and data flow, and to assess the recoverability of materials in different design options (Çetin et al., 2021). MP’s are seen as a powerful technique for realizing the closed-reversible material loop in all structures; including new, existing, or to be demolished (Ping Tserng et al., 2021). The use of MP’s also allows for the easy tracking and monitoring of a building's environmental performance throughout its life cycle, which can lead to the development of new economic models that support circularity in the building sector (Bertino et al., 2021). MP’s can also provide designers with input on material selections during the design phase (Kanters, 2020). Furthermore, MP’s are considered as an essential tool for achieving a circular built environment and prolong the lifespan of building materials (Rahla et al., 2021a).

This measure could support material efficiency (Akhimien et al., 2021) and reusability (Askar et al., 2022), as presented in table 6. See sub-subsection 3.4.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

Table 6: Linked criteria and measures.

Criteria	Measures								Frequency
	Use Material Passports	Use Recycled Materials	Use Dismantlable Design	Use Unitized Design	Use Digital Technologies	Use Regenerative Design Principles	Share Resources	Leasing Resources (Products as a service)	
Design for Disassembly			X	X					2
Material Efficiency	X	X		X	X	X			5
Energy Efficiency					X		X		2
Reusability	X	X	X	X			X	X	6
Durability									0
Flexibility			X	X			X	X	4
Functional Convertibility				X					1
Technological Refit-Ability								X	1
Ecological Resilience						X	X		2
Social and Cultural Acceptability							X		1
Biodegradability		X				X			1
Energy Renewability						X			1
Frequency	2	3	3	5	2	4	5	3	

3.4.5.2 Use Recycled Materials

Rahla et al. (2021b) described the term *"recycle"* as an operation that involves the recovery and reprocessing of waste materials into substances, materials, or products for the same or different purposes. In circular building design, the use of recycled materials involves combining materials that were previously used in other products after they reach their end of life (Rahla et al., 2021a).

In this context, the use of recyclable material can be integrated with material reuse during the design and construction phase (Eberhardt et al., 2022).

This measure can promote the criteria of material efficiency (Akhimien et al., 2021), reusability (Iyer-Raniga, 2019) and biodegradability (Dams et al., 2021), as presented in table 6. See sub-subsection 3.4.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

3.4.5.3 Use Dismantlable Design

In circular building design, the ‘’use dismantlable design’’ is the intentional configuration of building components and systems with the goal of allowing their disassembly and reuse at the end of a structure's life cycle (Bertino et al., 2021).

To facilitate disassembly in building design, designers can employ demountable building products and dry connections instead of wet connections (Geldermans, 2016).

This measure can promote DfD (Geldermans et al., 2019), reusability (Bertino et al., 2021), and flexibility (Geldermans et al., 2019), as presented in table 6. See sub-subsection 3.4.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

3.4.5.4 Use Unitized Design

Unity, often known as modularity/regularity, is the capacity to improve the consistency of a construction pattern in the building configuration. It can be promoted by including modularity in both spatial and physical dimensions of the building, which entails modularizing the organization of spaces and utilities as well as using standardized building products (Hamida et al., 2022). Employing modular design in circular building design entails purposefully creating building parts that are manufactured offsite before being assembled together at the project site (Kitagorsky, 2022).

To achieve a modular building design, designers can use various strategies, including standardizing the module size and utilizing demountable and movable parts that allows for easy customization (Dams et al., 2021 ; Eliote and Leite, 2022). Designers can use this strategy by dividing a product into adjustable parts that can be easily adapted and customized, resulting in facilitated flexibility and simplified maintenance (Antwi-Afari et al., 2022 ; Iyer-Raniga, 2019).

This approach could promote DfD (Eliote & Leite, 2022), material efficiency (Dams et al., 2021), reusability (Dams et al., 2021) and functional convertibility (Hamida et al., 2022) in circular building design by reducing waste and resource usage, while also enabling the reuse, relocation and recycling of building components (ARUP and Ellen MacArthur Foundation, 2020), as presented in table 6. See sub-subsection 3.4.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

3.4.5.5 Use Digital Technologies

Using digital technologies in buildings is in line with the principle of circular economy in buildings as it contributes to close the material loop. In buildings, applying material passports, utilizing Building Information Modeling (BIM), installing sensors, and using 3D printing are exemplary solutions for using digital technologies in buildings (Çetin et al., 2022 ; Iyer-Raniga, 2019).

Digitizing the built environment is effective to implement CE in the building sector, as it can provide an ongoing record and a tracking of the used materials, and thereby, facilitating the reuse of materials once they have reached their end-of-life (Rahla et al., 2021a). Using digital technologies can also reduce the consumption of non-resources by virtualizing and dematerializing the operational activities in buildings (ARUP, 2016).

In the context of building adaptability, using technologies can promote the capacity to meet the individual users by using user-centred technologies (Heidrich et al., 2017).

Accordingly, using digital technologies can promote energy efficiency (Iyer-Raniga, 2019) and material efficiency (Akhimien et al., 2021) in circular building design by the use of smart technologies to handle building maintenance concerns, as presented in table 6. See sub-subsection 3.4.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

3.4.5.6 Use Regenerative Design Principles

In the context of circular buildings, the use of regenerative design principles involves establishing renewability of resources (Rahla et al., 2021a), while also promoting the resilience of the ecological system (Iyer-Raniga, 2019). Exemplary solutions for the use of regenerative design principles are those pertain to the technique that promote energy neutrality, such as: net zero and renewable energy strategies, low-impact design and efficient water recycling (Iyer-Raniga, 2019).

This approach could promote material efficiency (ARUP, 2016), ecological resilience (Gibbons, 2020), biodegradability (Rahla et al., 2021a) and energy renewability (ARUP, 2016), as presented in table 6. See sub-subsection 3.4.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

3.4.5.7 Share Resources

In circular building design, resource sharing aims to operationalize multiplicity in the use of assets in order to maximize the efficiency of resource utilization (ARUP, 2016). Resource sharing can be promoted in different ways, including the provision of multipurpose facilities and sharable assets (Hamida et al., 2022).

For instance, designers can provide multipurpose spaces and sharable facilities (Ness and Xing, 2017).

This measure can align with the criterion of reusability (Atta et al., 2021), flexibility (Hamida et al., 2022), ecological resilience (Rahla et al., 2021b), social/cultural acceptability (Dewagoda et al., 2022) and energy efficiency (Rahla et al., 2021a), as presented in table 6. See sub-subsection 3.4.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

3.4.5.8 Leasing Resources (Products as a service)

Using leased products during the buildings life cycle is consistent with the circular economy principle in buildings since it helps to close the material loop (Xing et al., 2020). It means that suppliers maintain ownership of their products and materials, while customers pay for services (Ploeger et al., 2019). This can promote adaptability in the composition of buildings, as the leased components or products can be replaced easily with new products provided by

the supplier (Webb et al., 1997). For example, the façade of a building as a service, provides building occupants and owners with the benefits of well-maintained, functional, and adaptable exteriors, removing the need for complete ownership and accountability and allowing for cost-effective, variable alterations based on building type and stakeholder requirements (Azcárate-Aguerre, 2023).
As indicated by Hamida et al. (2023) this measure contributes to the criterion of reusability, flexibility and technological refit-ability, as presented in table 6. Because you can turn these products back to their provider and replace them with new one instead of discarding them or throw them away, and thereby, the provider can reuse them with another client or recycle/remanufacture the products that are turned back. See sub-subsection 3.4.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

3.5 CB23

Platform CB'23 (2021) connected different actors in the circular construction sector, both within the civil engineering sector and residential and utility construction sector. It was founded by the government and after five years of collaboration it resulted in a document where 7 guidelines for circular design were published. The following are the 7 guidelines:

1. Prevention.
2. Designing for Quality and Maintenance.
3. Designing for Adaptivity.
4. Designing for Disassembly and Reusability.
5. Designing with Reused Parts of Buildings.
6. Designing with Secondary Raw Materials.
7. Designing with Renewable Raw Materials.

3.6 Practical Guidelines

Guidelines are defined by Cambridge Dictionary (2022) as *''information intended to advise people on how something should be done or what something should be''*. They can be used to guide practitioners on how to implement and align related actions for the sake of achieving a certain target (Sahai and Casati, 2004).

In the building sector, they serve as an advice for professionals showing them how a certain quality should be achieved or what it should look like, such as how a predefined quality can be achieved in practice (Fox et al., 2002) or how a supportive tool can be used (Reeves et al., 2015). As guidelines is a type of informative tools, they can be supported with the use of visualization means (Hassanain et al., 2020).

Design guidelines should not be exclusive to theory or beliefs of individual designers, but rather they should incorporate empirical evidence (Park and Hannafin, 1993). For instance, in the adaptive reuse literature, Hamida and Hassanain (2023) developed a list of practical guidelines to enhance the performance of designers, contractors and building mangers in adaptive reuse of buildings based on a case study research which was guided by a literature-based conceptual model.

3.7 Summary of the Literature Review

This chapter presented a theoretical background on the key components – including concepts and themes – that are brought together in the conceptual model of this thesis. These components include adaptive reuse, vacant and obsolete buildings, circularity, adaptability and practical guidelines.

Adaptive reuse is the process of repurposing existing buildings or structures for new uses, rather than demolishing and replacing them. It can help to reduce vacancy and tackle the problem of building obsolescence by bringing a new life to underutilized or abandoned buildings. The circular economy is an economic system that focuses on reducing waste and maximizing resource efficiency by keeping materials and products in use for as long as possible within a closed-cyclic chain. In this context, adaptive reuse can also play a key role in operationalizing circular economy by extending the lifespan of existing buildings, reducing the need for new construction, reusing the assets, and conserving resources.
The benefit of adaptively reusing buildings in a circular manner is that it can extend the life of the building while facilitating adaptability for future changes.
Guidelines may contribute to this combination by providing a clearly coherent and informative tool that can guide professionals from the building industry or real estate market on how to adaptively reuse buildings in a circular manner, comprising a visualization of the theoretical principles in a way that is understandable and applicable in the real practice context.

The literature review revealed concluded with an identification of twelve criteria and eight measures for circular and adaptable adaptive reuse of vacant or obsolete real estate. The interconnectedness of them ideas is shown in table 6. Which shows that the criteria of *''reusability''* is promoted amongst most of the measures. While the measures of *''use unitized design''* and *''share resources''* are equally mostly represented amongst the criteria.

In conclusion, these criteria and measures were used as a guiding theory besides the findings of empirical research in the development of practical guidelines for the circular and adaptable adaptive reuse of vacant and obsolete real estate in the next chapters (see chapter 4).

4. Chapter 4: Case Studies

4.1 Overview

This chapter addresses the second twofold sub-question to what extent are circularity- and adaptability- related measures implemented in reusing vacant and obsolete buildings and what guidelines are being followed for that in the Netherlands. See sub- 2.3.2 for more information on this research approach. Therefore, this chapter presents a brief description and findings of 2 case studies on circular adaptive reuse projects, also shown in table 7.

4.1.1 Case study 1 (C1): Transformation of a partially vacant and obsolete office building to a residential property, Scheveningen, the Netherlands.

An obsolete and partially vacant multiple story building in Scheveningen was acquired by a real estate developer in the summer of 2019. Two years later, in 2021, the developer started the redevelopment process by proposing a function-free-mixed-use design with 34 apartments or 66 studio's and offices. The project completion is expected to be in the autumn of 2024, and the project is currently in the construction phase.

4.1.2 Case study 2 (C2): Transformation of 10 vacant office towers into mixed function building in Amsterdam, the Netherlands.

The municipality of the city sold 7 vacant office towers to a developer and kept 3 towers for redevelopment into an international school. The developer has repurposed the 7 towers as mixed-use towers by integrating 3 functions in each tower: restaurants/cafés on the first floor, workplaces and sharable spaces on the second floor, and apartments of various sizes on the upper floors. The other 3 towers have been transformed into an international school. Currently the buildings are in operational use and the project has been delivered.

4.2 Findings

This section discusses the findings obtained through various research methods, focusing on archival research, interviews and field observation.

4.2.1 Within case analysis of C1

Ten out of twelve CBA criteria for circular and adaptable building transformation were fulfilled in this project. The following is a description of the measures used in relation to the applied criteria in the project. Three professionals, with different roles, from the development firm were interviewed.

1: Design for Disassembly: Removal balconies, as demountable building components, were installed for easing dismantlability of building components. All building products were arranged and configured in accordance with the *"shearing layers"* concept. Interviewee E stated: *''Those 7 layers of Steward Brand are extremely important to design separately. This will make it possible to easily adapt these layers throughout the building life cycle based on each layer's lifespan''*. The separation of the building components based on Brand's (1994) *"shearing layers"* concept could help facilitate DfD, as explained by interviewee E. An example of this, is the application of removal balconies. For future use of the building the developer attached mounting points to the façade for the balconies. Interviewee C stated about this: *''To ensure that you can make changes cheaply, quickly and easily over time in the building.*

And if you want to change it to homes, for example, then the homes want outdoor space, then you have to be able to create balconies. That is the reason why these mounting points are attached to the facade.''.

2: Material Efficiency: Instead of demolishing the old structure and sending out old material for waste, the developer reused the old structure in the project redevelopment. This statement is taken from one of the reviewed documents by the developer: *''We accomplish an environmental savings of 30 to 40% compared to new building by reusing the structural framework. The building is harvested rather than demolished''*. In addition, this structure enables the use and reuse of columns which promotes material efficiency through its ease for adjustments. Interviewee A stated: *''We aim to identify the most sustainable approach for the project. When considering the structure, we look into the structure, for example, opting for building columns instead of solid concrete walls, as columns offer greater durability and flexibility for future program changes''*. The developer also applied an efficient design for all the shafts in the new floor plan as a way of optimizing and rationalizing the use of new materials in the project for future adjustments. Interviewee A stated: *''We already make space for shafts (installation space), that are not there. When formulating a space plan or designing plans, we consistently engage an architect or designer to create a functionally free space plan, serving as our blueprint. This plan lacks walls, representing the complete layout, including shafts. This approach aids in determining current and potential shaft placements, considering the smallest unit feasible within the structure for future adaptability. For instance, in a scenario where a 50-square-meter unit is available, and a demand for 25-square-meter units arises, subdivision is possible to meet the changing spatial requirements''*. Furthermore, the developer applied prefabricated concrete slabs in the design because these components offer possibility to be reused again. Interviewee A stated: *''We incorporate existing materials into our designs. Various material databases offer options for project applications. Additionally, we conduct analyses of commonly included materials in these databases. Utilizing this information, we base our design on specific materials, such as prefabricated concrete slabs, which can be sourced from other projects, promoting reuse and sustainability. This approach ensures materials remain in circulation, minimizing the need for demolition''*.

3: Energy Efficiency: The developer of this project plans to monitor the energy usage with sensors and collect data to make it more efficient for the user. Interviewee C stated: *"Sensors need to mine data, which entails understanding how a building is used. This involves identifying the areas where people gather, the types of individuals present, and their location within the building. Additionally, it includes determining when specific heating elements activate and which parts of the building experience elevated temperatures, especially on the southern facade during summer. Such data is intended to raise awareness among users about their building utilization patterns."*.

4: Reusability: Building components such as existing staircase are reused. In addition, portions of the façade, the core and the old shafts were reused. Interviewee C stated: *''In addition, within the structure, there existed a staircase, which has been repurposed. Furthermore, portions of the façade, the core, and shafts have also been reused''*. The following statement is stated in one of the reviewed documents: *''The existing staircase and steel columns will be reused in the building''*.

5: Durability: An example of a durable measure is the type of glass that was used for the façade. The building will be operated by a hotel (short-stay/long-stay) in the first twenty years. From an acoustic point of view, there are no strict requirements for the type of glass. However, if the building will be used as housing, the glass needs to be thicker for acoustic requirements. By implementing thicker glass the building is more future-proof. Interviewee B stated: *''There are no sound restrictions for the building exterior when constructing for a lodging facility, such as (name of building), which is a hotel. This indicates that, in the most cost-effective situation, we could build a property without acoustic glass. However, we have chosen to follow the most strict residential function standards. This ensures that we have a high-quality building that can be used into a residential building in the future with minimum glass replacement''*. Furthermore, within Steward Brand's (1994) layers, the structure and skin have the longest lifespan and within those layers CBA-related measures will have most impact on durability. Interviewee B stated: *''So, the layers with the longest lifespan, the structure and the skin, must be designed precisely. This ensures that within these two layers, which have an extended lifecycle, continuous adjustments can be made''*.

6: Flexibility: It is critical to design a building that is easily adaptable to current and future needs within the context of circularity. The following statement was found in one of the reviewed documents: *''The building was created to be completely flexible and demountable. In its initial application, a wall system is used to combine many studios into a bigger two or three-bedroom apartment''*. Flexible walls that can be used to separate or combine spaces are used to promote the flexibility to reconfigure the spaces. Interviewee A stated: *''We applied flexible walls that allow for flexible unit size''*. These flexible walls allow the user to easily adjust apartment size.

7: Functional Convertibility: The principles of *"function free building"* were brought together and embraced in the transformation of this project, where functional convertibility was clearly applied, also called dynamic approach by the developer. Interviewee A stated: *''When we build something, we always do it with this so-called function free approach''*. Interviewee C explained why the developer chose this approach: *''Functional free building approach represents adaptability at its maximum. Therefore, when a building attains functional freedom, it achieves maximum adaptability. This means that the building can be economically and technically easily adjusted to accommodate all future changes''*. This is mainly achieved by designing the floor plan in such a way that elements like stairs and shafts are configured and aligned to ensure that a functional transformation can be easily carried out. Interviewee B explained how the developer achieves this *''function free building''* design: *''To simplify this for architects, we advise designing for three or four different functions. Ensure that their floor plans can be overlaid reasonably, with consistent structural elements like shaft positions. They should all align on the same framework. Consider the placement of balconies and natural light. Make sure everything fits together harmoniously. Create clear access points, including logical locations for stairwells, shafts, elevators, and corridors. Address all function-specific elements separately, gradually removing them, resulting in a functionally flexible floor plan''*. In essence, including a *''function free design''* design entailed identifying and considering prospective functionalities that could be integrated in the future, as well as assessing their legislative and technological requirements. The recognized functions in this case include hotel (short-stay/long-stay), residential, and office purposes. This is also supported by one of the archival documents provided by the developer: *''The building is a multi-purpose asset. Each* *floor can be readily transformed into living, working, or staying spaces''*. Designing for different functions contributes to developing a building with a longer lifespan and low risk of long vacancy, which has been fostered in this case. Interviewee B stated: *''We feel that this strategy has intrinsic value as a building capable of continuously adjusting to changing user needs throughout time. This results in a low vacancy risk because it is still available to everyone and a higher value for investors''*. This higher value for investors, is stated in one of the reviewed documents: *'' The building has a lower vacancy risk and a larger market appeal due to its dynamic character. Furthermore, it entails much cheaper transformation costs. When compared to traditional structures, these benefits result in higher rental rates and value appreciation''*. The developer reused the old structure and extended its useful life. Interviewee C explained why: *''We have examined the office grid. Therefore, the building should be point-loaded, not uniformly distributed. This entails the incorporation of columns, a feature present in the building. There is no load-bearing facade, which is also not applicable in this case. Furthermore, the building offers a comfortable floor-to-ceiling height. These factors serve as determinants for us to consider the reuse of the existing structure''*. In this context, the dimensions of the grid of the old structure are designed in such a way that no changes in its proportions are required to fit the functions that will be incorporated into the design of the new building. Interviewee A stated: *''The grid of the structure was suitable for different functions''*.

8: Technological Refit-Ability: The developer is developing a smart building. The following statement is stated in one of the reviewed documents: *''The building is the first pilot project in collaboration with an external advisor to develop a smart building. The functionally adaptable building is traditionally outfitted with an IP backbone and an IoT network. We can then decide what data points to collect for each individual use case, in cooperation with the users. Based on these specifications, we can then build a sensor network''*. It will be a foundation for future progressive technological enhancements; an innovative sensor system to collect data is an example that can be used with the IP backbone and IoT network. Interviewee C stated: *"The acquisition of such data is intended to serve the dual purpose of fostering user awareness regarding their interactions with the building and facilitating collaborative discussions on progressive enhancements to the building over time''*.

9: Social and Cultural Acceptability: Social and cultural acceptability are achieved by promoting restaurants and other facilities in the area, also by reintroducing the classic architecture that has been on this place. For social acceptability reasons, on one hand, the developer perceives the connection between the project and the surrounding community as a necessary aspect for the community. In the reviewed documents the following is stated about this: *''The building becomes a place of significance as a result of its beloved character, a building that is connected to the city and fulfils current and future socio-cultural demands. It also contributes to the well-being of its occupants''*. Interviewee C explained how this is achieved: *''Our operator is guided by the concept of "Unlock the Neighborhood." This implies an encouragement for individuals to explore the local community. Specifically, they strongly desire guests to stay with them and venture outside for dining and recreational activities. The overarching goal is to stimulate the surrounding area and ensure sustained economic growth. Consequently, within the ground floor (Plint), we have designated shared spaces, including a living room, a reception area, and a workspace''*. Furthermore, the architectural aspects of classical architecture have been preserved in order to gain social and cultural acceptability.

Interviewee C stated: *''We refer to it as "preciousness." Thus, you reintroduce a piece of history. When you bring back history, reconstructing a building that has suffered damage and integrating it with a new facade in the same spirit, it is referred to as preserving history. Consequently, historical value is reinstated. This holds significant value for the city, as well as for the surrounding residents and inhabitants''*. The developer considered the preservation of the classical architectural elements as a means to increase the cultural acceptability of the building by the surrounding community. The former asset, as shown in figure 7, which intrinsically had cultural and aesthetic values, was destroyed by a fire. By putting emphasis on architectural elements, like details, the developer promotes social and cultural acceptability. Interviewee A stated: *''An approach in a lot of buildings that are still standing today, is that they are detailed and that they have a kind of craftsmanship that is shown through the facades and that's why they're still there''*.

Figure 7: First picture is taken before the development, second one shows the desired result and third was the building before the fire (Source: archival documents shared by developer).

10: Energy Renewability: The building will be fully self-generative as stated in one of the reviewed documents provided by the developer: *''A nearly self-sustaining structure in which electricity is generated on the roof via PVT solar panels, in addition to a sustainable shared bicycle and automobile system''*. This solution is implemented through installing PVT solar panels on the roof.

4.2.2 Within case analysis of C2

Eleven out of the twelve CBA criteria were applied by implementing different measures. The following is a description of the measures used in relation to the applied criteria in the project. Four professionals employed by different parties that executed the redevelopment of the project were interviewed.

1: Design for Disassembly: An example of DfD, in the international school, is the use of demountable floor-ceiling-mounted service columns. Interviewee G stated: *''The floor-ceiling-mounted service columns are demountable and relocatable. It is possible to extract or add connections to them. In this manner, we attain a high degree of flexibility in configuring the layout, determining the locations, and specifying the quantity of electrical outlets and data points throughout the building''*.

2: Material Efficiency: The design team of the international school found glass walls and donated them to a party that applied them in one of their projects. Interviewee G stated: *''There were quite a substantial number of glass interior walls, relatively new components of approximately 3 to 4 years old, featuring significantly thick glass. Discarding them after only four years would be highly wasteful. Consequently, a company, assumed responsibility for these partitions. The company repurposed the glass facades elsewhere, essentially as a charitable contribution. The profitability, in this case, stemmed from the fact that the party receiving them not only accepted them at no cost but also undertook their disassembly and removal''*. The design team of the international school implemented another solution demonstrating material efficiency through the centralization of ventilation as a way of optimizing and rationalizing the use of new materials in the project. Interviewee G stated: *''For instance, centralizing air extraction was implemented in the corridors, minimizing the need for ventilation ducts throughout the entire building. This approach was driven by both the goal of reducing material usage and the challenge of accommodating these ducts within the confined space above the lowered ceilings. Therefore, central extraction proved to be a mutually beneficial solution, resulting in substantial savings in ductwork and grilles''*.

3: Energy Efficiency: In the international school, motion-tracking sensors have been installed to rationalize energy consumption in the unoccupied spaces. Interviewee F stated: *''Motion detectors, presence sensors in every room, serve not only for lighting but also for heating, encompassing the entirety of climate control, including ventilation, heating, and lighting''*. In addition, the lighting fixtures were replaced with LED, as an energy efficient measure. Interviewee G stated: *''We engaged a supplier who collected all the LED, TL, and PL fixtures. Subsequently, the supplier removed the conventional TL and PL technologies and replaced them with LED technology, while preserving the entirety of the fixtures. Thus, the entire housing, as commonly observed, remained intact. In this manner, a new LED technology and light source, such as an LED strip or spotlight, were integrated, and the fixtures were then returned''*.

4: Reusability: Many building materials and components have been reused in this redevelopment project. The following statement was found in one of the provided documents by the design team of the international school: *''Many building services components can be entirely restored to new condition for a cost-neutral or cost-effective price, even if they are over 30 years old. This method skips the typical process of completely gutting the structure and then renovating it, instead focusing on determining which components can still be used successfully''*. One of the reused products were the elevators that have been repaired and reused by the international school. Interviewee D stated: *''The elevators have also been completely repaired''*. Besides the elevators, many other installations have been reused by the international school. Interviewee D stated: *''What we were able to reuse included: floor-ceiling-mounted service columns, the heating system, electricity cables, ventilation grilles, fire hose reels, air handling units, sprinkler system, dry fire hydrant systems, lighting fixtures, façade maintenance installations, rainwater drainage systems, water pipes, lightning protection, patch cabinets, architectural carpet tiles, all window frames and ceiling panels''*. Most of these installations were dismantled, repaired, and reassembled. Interviewee D explained the following: *''In this case, it is a deliberate choice to have the disassembly performed by entities that also have the potential to provide reassembly services. It is precisely individuals skilled in reassembly who disassemble in a manner conducive to eventual reuse.*

This is indeed of paramount importance''. In the international school, old floor-ceiling-mounted service columns were reused in the building. Interviewee G stated: *''In the majority of the building, we have implemented floor-ceiling-mounted service columns. These columns, essentially containing data points and electricity, have been repurposed from the old structure''*. Another example of reusing materials was the reuse of ceiling panels. Interviewee G stated: *''There were still a considerable number of intact ceiling panels available. The supplier proceeded to coat them in the specified colour as provided by the architect. Subsequently, these panels were returned and installed''*. In addition, the reuse of kitchens components in the international school is another example of reusing building materials. Interviewee G stated: *''There were kitchens in the building from the bank's previous occupancy, and the school desired to retain certain components from those kitchens. This decision was made with the intention of utilizing them for lunch preparation before the break. Consequently, the school effectively repurposed these elements, although some parts of the kitchen underwent renewal. Not all functionalities of the existing kitchen could be retained for reuse by the school. Therefore, it underwent partial reuse and partial renovation''*. Another example is the reuse of the ventilation system in the international school. Interviewee D stated: *''The ventilation system was completely disassembled, cleaned thoroughly, and all parts that could be reused were indeed repurposed''*. In the international school, the air handling units (AHU) had reached the end of their operational lifespan; however, their lifespan was extended through repairing and reusing them. Interviewee G stated: *''Notably, the air handling units in question were over 25 years old, and it is commonly asserted that installations of this kind typically have a maximum lifespan of 25 years. It is not a case of refurbishing them after 5 or 10 years and then expecting another 15 years of service, ultimately reaching the 25-year mark. Instead, these units are now actually being utilized for durations exceeding 25 years. A crucial aspect in this regard is engaging genuine specialists, such as a supplier of such units, to thoroughly assess and ensure a renewed operational lifespan of 10 to 15 years''*. The former user of the buildings left a lot of furniture items; thereby, these items have been reused in the international school. Interviewee F stated: *''The bank, upon vacating the building, left a considerable amount of furniture for us. In their view, this serves as a form of donation and aligns with the circular concept; otherwise, it would have been discarded''*. Finally, the developer of the mixed-use towers reused all the window frames. Interviewee E stated: *''We deliberately retained those in the window frames and installed new glass instead of replacing the frames entirely''*.

5: Flexibility: The walls dividing the classrooms of the international school are not integral to the load-bearing structure, which promotes flexibility. Interviewee F stated: *''The true flexibility lies in the absence of walls in classrooms that form part of the building's load-bearing structure. Consequently, if there is a shift in the educational paradigm or a change in approach in the next 10 to 15 years, one can easily demolish or relocate a classroom wall to expand a space''*. The developer integrated working space next to the rented office spaces in the corridor to facilitate their utilization by both residents and office tenants. Interviewee E stated: *''Suppose you have 20 people. Then, for example, you would rent an office with 12 workstations. When everyone is present, some individuals can utilize the internal street for work. This way, you achieve the same capacity with less spatial footprint, efficiently accommodating everyone. I would describe it as space-efficient''*. In addition, some of the rooms next to the rented office spaces are part of this open floor plan. Interviewee E stated: *''Within the internal street, we have a collection of well-appointed meeting rooms.*

Intentionally, we refrained from converting them into residential units, choosing to preserve them in their original state. Currently, these spaces continue to function as meeting rooms or are repurposed as smaller meeting areas''. Thus, these spaces can also be used by both residents and office tenants. Interviewee E stated: *''Residents occupying upper levels have the convenience of utilizing the internal street as a workspace''*. Furthermore, the developer combined large and small-sized offices in the mixed-use towers to increases the useful life of the building. Interviewee E stated: *''Down in that street, we deliberately created both smaller and larger offices, allowing for the expansion of a company. As a company grows, it can transition to a larger office space''*.

6: Functional Convertibility: The building configuration - through the design of its towers with a central core that allows daylight through the roof of the towers all the way down, as shown in figure 8, - allows for meeting the requirements for natural light in residential spaces. Therefore, the mixed-use towers were usable for easy transformation. The developer did this by transforming office rooms into dwellings. Interviewee E stated: *''And these were offices, each with a maximum distance of six meters to a window. This space can, therefore, be converted into suitable residential units''*. They can also be easily reverted to office spaces. Interviewee E stated: *''It is possible that you might want to convert the upper levels back into office spaces. In that case, you can simply remove the residential units''*. The international school benefits from the same feature of daylight through the core, it makes it easier to adapt to other use of space. Interviewee F stated: *''Due to the atrium in the towers, light penetrates through the core, and this design allows for considerable flexibility in reconfiguring the layout on those floors''*. Furthermore, the developer over-dimensioned the apartments in the mixed-use towers to assure ease for future conversion into different apartments types. Interviewee E stated: *''I have always believed that if you design residential units with a generous spatial layout, they inherently become adaptable. This is because they can accommodate not only a couple but also a family. For instance, a three-bedroom residence can easily be transformed into a single occupancy dwelling or another type of residence''*.

Figure 8: Central core allowing the daylight to enter the building through transparent skylights (Source: picture taken during field research on Thursday, 23-November 2023).

7: Technological Refit-Ability: Digital twin is facilitated as an enabling technology in the redevelopment of the international school. Interviewee D stated: *''We received an entire archive, all on paper. There used to be no reason to digitize it, now it is, so now it is digitized in BIM''*. All the material used in the property can now be traced in the BIM model, which can pave the way for their replacement and the provision of new products. Interviewee G stated: *''The architect, in collaboration with another architect, generated a Building Information Modeling (BIM) model. From a structural perspective, scans, presumably point cloud scans, were employed to capture the contours. This facilitated the assignment of materials within the model. Consequently, the design was visually rendered with precision. Subsequently, our team independently crafted the design in 3D, incorporating the mechanical and electrical installations. The resulting design is quite aesthetically pleasing''*.

8: Ecological Resilience: The project also demonstrates the promotion of ecological resilience through the incorporation of plants in the classrooms at the international school. The following is stated about this in one of the reviewed documents: *''It has been demonstrated that classrooms with abundant plants contribute to a 20% increase in student concentration and higher scores in assessments''*. To facilitate the growth of plants inside the international school, the design team applied the right lighting. Interviewee G stated: *''Our contribution was ensuring that the plants receive sufficient light, especially in areas where the building's configuration, including its angles and forms, did not permit ample natural light. This was done to guarantee that the required illumination for the plants was consistently met''*.

9: Social and Cultural Acceptability: The developer gained social and cultural acceptability from the surrounding community by developing a mixed-use property. One example is the creation of different sizes of apartments with different rental prices to attract different tenants from different classes. The following was stated in the published archives: *''I think this choice will also bring other people to this part of the city''*. Another example of gaining social and cultural acceptability through mixed-use is mentioned in one of the reviewed archival documents: *''Transformation from monotonous office to vibrant mixed-use''*. Some of those are public spaces. For instance, a courtyard with catering facilities below the apartments. Following is a quotation from one of the published archives: *''Make it open and connected for everyone in Amsterdam South-East to enter''*. Individuals can enter the buildings during the daytime, as the entrance to the courtyard is located at the side of the big busy square at Bijlmerplein. Interviewee E stated: *''The courtyard below is entirely public, and if you wish to access the street for a meeting, for instance, you obtain a pass that allows entry. Consequently, there is a significant amount of foot traffic in that street. However, it is one level less public, as businesses can also operate in that area''*. Furthermore, an event space is created on the rooftop by the developer to be used as a space for social events. The following statement was found in the published archives: *''An event space on the roof that can be reached by elevator''*. Interviewee E stated: *''Visitors would register downstairs, receive a ticket, and then proceed upstairs, which is essentially an extension of the public accessible courtyard. Visitors take the elevator through the residential tower, arriving at the rooftop terrace with its separate exit and entrance''*. The international school employs a similar system for organizing cultural activities outside the school's regular working hours. Interviewee F stated: *''To facilitate easy organization of shared use. We are still in the initial phase; we've only been at it for two months. However, the first choir rehearsals have already taken place, and the Gospel choir has also visited once''*.

10: Energy Renewability: Solar panels on the roof allow the international school to partly use solar energy generated on the roof. Interviewee F stated: *''We also have solar panels on the roof. We have approximately 100 solar panels installed, although our building consumes a substantial amount of electricity''*.

4.3 Cross-Case Analysis and Discussions

This section presents and discusses a cross-case analysis of the two case studies to identify and replicate common patterns in the circular and adaptable design-oriented measures. The aim is to gain insights into the measures employed in transforming C1 and C2. Table 7 presents a cross-case analysis of the two case studies, in which the shared and relevant measures between the two cases are included.

4.3.1 Fulfilment of Criteria for Circularity and Adaptability in C1 and C2

C1 and C2 promoted eleven out of twelve criteria related to circular and adaptable building transformation. Both cases prioritize design for disassembly, material efficiency, energy efficiency, and reusability. Flexibility, functional convertibility, social and cultural acceptability, technological refit-ability and energy renewability emerge as common principles for adaptability and circularity. See sub-subsection 3.3.4 for more information on the criteria for circular and adaptable adaptive reuse of buildings.

1: Design for Disassembly: In C1, the application of DfD in façade design is evident through the use of demountable building components, such as removal balconies. These components were strategically designed to adhere to "shearing layers" concept by Brand (1994), facilitating ease of disassembly for future adjustments. The incorporation of mounting points on the façade for balconies enhances adaptability.

C2 adopts another DfD strategy in the international school by utilizing demountable floor-ceiling-mounted service columns. This measure provides a high degree of flexibility in configuring layouts and determining the quantity and locations of electrical outlets and data points throughout the building.

2: Material Efficiency: Material efficiency in C1 is achieved through the reuse of the old building, emphasizing a significant reduction in the carbon footprint. The use of prefabricated concrete slabs and a functional design for new floor plan shafts optimizes the use of new materials, minimizing the need for demolition, and thus, minimizing waste development.

C2 demonstrated the application of material efficiency by repurposing glass panels, centralizing the building ventilation, and donating reusable building components to external parties.

3: Energy Efficiency: Energy efficiency measures in C1 include the installation of sensors for monitoring energy usage. These sensors aim to collect data on building utilization patterns, contributing to a more energy-efficient environment.

In C2, motion-tracking sensors and LED lighting were installed to contribute to energy efficiency. The motion detectors serve multiple purposes, including lighting, heating, ventilation, and climate control, promoting sustainable energy practices in unoccupied spaces.

4: Reusability: Various building components were reused in C1 to promote reusability, such as elevators, staircase, façade portions, and core elements. The deliberate choice to disassemble and reassemble components ensures their potential for future reuse.

In C2, reusability is strongly promoted in many building services and components through restoration. Elevators, ventilation systems, lighting fixtures, and other installations are meticulously disassembled, repaired, and reused, showcasing a commitment to circular practices.

5: Durability: C1 promotes durability by selecting glass for the façade that meets future acoustic requirements, contributing to the building longevity. The strategic design of the structure and skin, following Brand's (1994) layers, focuses on arranging the components according to their expected lifespans, ensuring a futureproof composition of building.

6: Flexibility: Flexibility in C1 is achieved through the installation of movable walls that allow for easy adjustment of apartment sizes and design of an open floor plan.
C2 promotes flexibility by adopting an open floor plan with walls not integral to the load-bearing structure. The intentional design of the internal street and adjacent rooms facilitates shared use by both residents and office tenants.

7: Functional Convertibility: C1 promotes functional convertibility by designing a building with a *"function free"* approach combined with movable walls, enabling easy adjustments to accommodate changing user needs. The deliberate consideration of prospective functionalities, such as hotel, residential, and office purposes, results in a building with a longer lifespan and reduced vacancy risk.
C2 applies functional convertibility by transforming office rooms into dwellings including excess capacity to promote adaptability. The design of towers with a central core allows for easy conversion of office spaces to residential units, ensuring adaptability for future needs.

8: Technological Refit-Ability: C1 promotes technological refit-ability by developing a smart building with an IP backbone and an IoT network. The use of sensors and data collection facilitates collaborative discussions with the users on progressive enhancements.
C2 leverages technology by using a digital twin and Building Information Modeling (BIM). The digitization of archival data enhances traceability of materials, paving the way for replacement and the provision of new products in the future.

9: Ecological Resilience: C2 actively promotes ecological resilience by incorporating plants in classrooms, contributing to improved student concentration and assessment scores. The consideration of lighting conditions for plant growth demonstrates a commitment to ecological sustainability.

10: Social and Cultural Acceptability: Social and cultural acceptability is achieved in C1 by preserving architectural elements and reintroducing classic architecture. The mixed-use property design, with public spaces in the hotel lobby and empowerment of local entrepreneurs, fosters community engagement and cultural appreciation.
C2 further enhances social and cultural acceptability through a mixed-use development, offering apartments with different sizes and rental prices; thereby, attracting tenants from different classes. Public spaces, including a public courtyard and event space on the rooftop, contribute to community engagement and cultural vibrancy. The intentional design of accessible areas and the provision of cultural activities outside regular hours showcase a commitment to social and cultural acceptability and community involvement.

11: Energy Renewability: Energy renewability is explicitly addressed in C1 through the installation of PVT solar panels.
C2 actively promotes energy renewability by installing solar panels on the roof. Approximately, 100 solar panels contribute to the generation of solar energy, which is in line with the principles of environmental sustainability by the means of reducing the environmental impact of the building.

4.3.2 Replicated Measures for Circularity and Adaptability in C1 and C2

Five out of eight measures for CBA in adaptive reuse were taken in both projects. See sub-subsection 3.3.5 for more information on the measures for circular and adaptable adaptive reuse of buildings.

1: Use of Dismantlable Design: Both cases implemented measures that promote disassembly and potential reuse of building components. C1 introduced removable balconies, facilitating future reconfiguration and disassembly, while C2 provided demountable floor-ceiling-mounted service columns to allow for greater flexibility during the building life cycle.

2: Use of Unitized Design: Both cases show the adoption of modularity in the spatial and physical design of the building. C1 incorporated the dimensions of the old steel structure's grid and efficient shaft design, promoting a modular approach. In addition, C1 also showed the application of movable walls, easing adaptability to promote functional convertibility. C2 utilized unitized design by incorporating standardized walls which are separated from the structure, offering a mix of smaller and larger offices, and fostering adaptability and efficiency in space utilization.

3: Use of Digital Technologies: Sensors in combination with IP back bone and IoT network for energy data collection were utilized in C1 as an enabling technology for energy efficiency. In C2, a digital twin for tracing building materials was utilized with the help of a BIM-model. These measures enhance energy efficiency, material efficiency and technological refit-ability.

4: Use of Regenerative Design: PVT solar panels were installed in C1 to contribute to energy renewability. In C2, solar (PV) panels were installed to also promote energy renewability.

5: Share of Resources: Shared spaces, including a living room, a reception area, and a workspace, also shared vehicles, sustainable shared bicycle and automobile system were applied in C1 promoting flexibility and social and cultural acceptability. In C2, donation of glass panels promoting material efficiency and shared multiuse spaces including public-accessible conference rooms and working space are applied which enhances flexibility and social and cultural acceptability.

4.4 Summary and Reflection on the Case Studies

The fulfilment of one criterion, namely *'biodegradability'* was not fulfilled in both cases. Three measures from the literature, namely *''use of material passports'', ''use of recycled materials''* and *''leasing resources'',* 'were not implemented in both cases as well. However, *''leasing resources''* was in the design plans of C1, but was not implemented for feasibility-related reasons associated with the consequences of the COVID-19 pandemic on the building industry and real estate market.

As shown in table 7, eight other measures were implemented and not explicitly mentioned in the literature study, namely:

1: Design for Excess Capacity: This measure was addressed in both cases, albeit with different approaches. C1 over-dimensioned windows to promote durability, while C2 over-dimensioned the size of apartment units to promote functional convertibility.

2: Reuse of old Building Products and Components: This measure was implemented in both cases, with different examples of reused or repaired building components to promote material efficiency and reusability.

3: Preserving cultural elements: This measure was implemented in both cases, with different measures, through different building elements. Such as preserving classical building components in C1 and monumental parts in C2.

4: Community Involvement: in C1 by empowering local entrepreneurs, and in C2 by providing a mixed-use property with public-accessible courtyards, meeting rooms, and rooftop event spaces or by different unit sizes to attract different tenants. These measures contribute to social and cultural acceptability in adaptive reuse projects.

5: Use more Green: This measure was implemented in C2 through the provision of plants in classrooms, corridors, and around the building for a healthier environment.

6: Optimization of Resource Utilization: This measure was implemented in C2 by centralizing air extraction units to promote material efficiency.

7: Elimination of Waste: This measure was implemented in C2 by donating glass panels for recycling which promotes material efficiency.

8: Use of Energy Efficient Lighting/Ventilation: This measure was implemented in C2 by utilizing LED technology for the lighting and motion-tracking sensors to optimize energy use in empty rooms promoting energy efficiency.

In conclusion, the findings of the cross-case analysis in table 7 offer valuable insights in developing guidelines for architects, engineers, and contractors (AECs) as well as building managers aiming to replicate successful circular and adaptable adaptive reuse projects for different building types. The cross-case analysis revealed varied implementation of circular and adaptable adaptive reuse measures, with consistent use of *"unitized design"* and *"reuse of old building products,"* while *"use of recycled materials"* and certain environmentally-oriented measures showed limited application in the two cases.

Table 7: Circular and adaptable adaptive criteria and measures for reuse of buildings employed in transforming C1 and C1.

Criteria	Case	Measures
1. Design for Disassembly	C1	Use of Dismantlable Design: 1. Installation of removable balconies. Use of ''shearing layers'' in Design: 2. Separation of the layers according to their projected lifespan
	C2	Use of Dismantlable Design: 3. Provision of demountable floor-to-ceiling-mounted service columns.
2. Material Efficiency	C1	Use of Unitized Design: 1. Unitization of grid dimensions. 2. Efficient design of shafts in floor plan. Reuse old Building Products and Components: 3. Reuse of the old steel structure with columns allow for easy adjustments. 4. Utilizing prefabricated concrete slabs.
	C2	Elimination of Waste: 5. Donating glass panels. Optimization of the Utilization of Resources: 6. Centralizing air extraction units.
3. Energy Efficiency	C1	Use of Digital Technologies: 1. Sensors to collect data about energy.
	C2	Use of Energy Efficient Lighting/Ventilation: 2. Utilization of LED technology to reduce energy consumption of lighting. 3. Use of motion-sensors to optimize energy use.
4. Reusability	C1	Reuse old Building Products and Components: 1. Reuse of old steel structure, 2. Repair of old staircase and elevators, 3. Reuse of old shafts and façade.
	C2	Reuse old Building Products and Components: 4. Repair of elevators. 5. Demountable floor-ceiling-mounted service columns. 6. Repair and reuse ceiling panels. 7. Repair and reuse kitchen components. 8. Repair and reuse air handling units. 9. Reuse of old furniture items. 10. Repair and reuse of window frames.
5. Durability	C1	Design for Excess Capacity: 1. Over-dimensioning the windows during replacement of façade components. Use of ''shearing layers'' in Design: 2. Separation of the layers according to their projected lifespan.

	C2	N/A
6. Flexibility	C1	Use of Unitized Design: 1. Installation of movable walls. Share of Resources: 2. Provision of multifunctional spaces.
	C2	Use of Unitized Design: 3. Separation of walls from structure. Share of Resources: 4. Provision of multifunctional spaces.
7. Functional Convertibility	C1	Use of Unitized Design: 1. Design for *''function free building''.* 2. Installation of movable walls.
	C2	Design for Excess Capacity in Design: 3. Over-dimensioning the size of apartment units. Use of Unitized Design: 4. Separation of walls from structure. 5. Provision of a transparent central core.
8. Technological Refit-Ability	C1	Use of Digital Technologies: 1. IP backbone and IoT network.
	C2	Use of Digital Technologies: 2. Provision of digital twin for tracing the building materials.
9. Ecological Resilience	C1	N/A
	C2	Use more Green (Healthier): 1. Provision of plants in classrooms.
10. Social and Cultural Acceptability	C1	Involving Communities: 1. Empowerment of local entrepreneurs to involve community. Preserving Culture: 2. Preservation of the classical architectural elements to conserve culture.
	C2	Involving Communities: 3. Provision of different sizes of apartments / office, 4. Provision of public-accessible courtyards, meeting rooms, working places and rooftop event space, 5. Provision of a multifunctional design. Preserving Culture: 6. Preservation of monumental parts.
11. Biodegradability	C1	N/A
	C2	N/A
12. Energy Renewability	C1	Use of Regenerative Design Principles: 1. Installation of PVT panels.
	C2	Use of Regenerative Design Principles: 2. Installation of PV panels.

5. Chapter 5: Practical Guidelines for Circular and Adaptable Transformation of Vacant and Obsolete Buildings

5.1 Overview

This chapter addresses the third sub-question, namely *"how can guidelines guide professionals on how to promote circularity and adaptability related measures in the reuse of vacant and obsolete buildings?"* Therefore, this chapter presents practical guidelines that are developed based on outcomes from the literature and case studies, and validated by interviews with professionals. See section 2.3.3 for more information on this research approach. The guidelines were developed to be used as a guiding instrument for the design for circular and adaptable transformation of vacant and obsolete buildings.

5.2 Formulation of Guidelines

The following thirteen guidelines were formulated and proposed in line with all the identified criteria and measures from theory and practice (see table 8 on next page). The guidelines were synthesized in a manner that can foster their usability by all professionals aiming for designing building transformation projects for circularity and adaptability.

1: Prioritize Design for Disassembly (DfD): Standardize construction elements in terms of their connections and dimensions to facilitate replaceability and accessibility, while avoiding unnecessary overlap of diverse building components and elements. Thereby, this will embody adaptability for future adjustments, particularly fostering circularity and longevity.

2: Maximize Material Efficiency: Minimize the use of new material by reusing existing components and repairing deteriorated elements. Additionally, other material reprocessing measures may include repurposing and renovating building assets. For new building assets, using recycled materials and second-hand products can be implemented to maximize material efficiency as well as foster the reusability of assets in the long-term.

3: Optimize Energy Efficiency: Enhance the energy use and management in the building by installing smart building technologies, such as sensors and data collection systems, that monitor energy efficiency. Other systems can encompass motion-tracking sensors and LED lighting, which reduce energy consumption in unoccupied spaces.

4: Promote Reusability: For existing assets, restore old building components and systems and install them using dry connections to promote their reusability afterwards. For new assets, utilize standardized and modular building components, elements and items in terms of measurements to facilitate their reuse afterwards as well as enhance the efficiency of material usage in the long-term.

Table 8: Alignment and interrelationships between the guidelines, measures and criteria.

Relevant criteria	Measures	Guidelines
1. Design for disassembly, material efficiency, reusability and flexibility	1. Installation of removable balconies. 2. Separation of the layers according to their projected lifespan. 3. Provision of demountable floor-to-ceiling-mounted service columns. 4. Use of dry connections instead of wet connections. 5. Use Unitized Design.	1. Prioritize Design for Disassembly (DfD)
2. Material efficiency and reusability	1. Unitization of grid dimensions. 2. Efficient design of shafts in floor plan. 3. Reuse of the old steel structure with columns allow for easy adjustments. 4. Utilizing prefabricated concrete slabs. 5. Donating glass panels. 6. Centralizing air extraction units. 7. Use Material Passports. 8. Use Recycled Materials. 9. Use Unitized Design. 10. Use Regenerative Design Principles.	2. Maximize Material Efficiency
3. Energy efficiency	1. Sensors to collect data about energy. 2. Utilization of LED technology to reduce energy consumption of lighting. 3. Use of motion-sensors to optimize energy use. 4. Use of LCA. 5. Share Resources.	3. Optimize Energy Efficiency
4. Reusability and material efficiency	1. Reuse of old steel structure. 2. Repair of old staircase and elevators. 3. Reuse of old shafts and façade. 4. Repair of elevators. 5. Demountable floor-ceiling-mounted service columns.	4. Promote Reusability

	6. Repair and reuse ceiling panels. 7. Repair and reuse kitchen components. 8. Repair and reuse air handling units. 9. Reuse of old furniture items. 10. Repair and reuse of window frames. 11. Use Material Passports. 12. Use Recycled Materials. 13. Use Dismantlable Design. 14. Use Unitized Design. 15. Share Resources. 16. Leasing Resources (Products as a service).	
5. Durability	1. Over-dimensioning the windows during replacement of façade components. 2. Separation of the layers according to their projected lifespan. 3. Selection of materials with high durability and low maintenance needs.	5. Enhance Durability of Building Components
6. Flexibility and reusability	1. Installation of movable walls. 2. Separation of walls from structure. 3. Provision of multifunctional spaces. 4. Design open floor plans. 5. Leasing Resources (Products as a service). 6. Use Dismantlable Design. 7. Share Resources.	6. Provide Configurational Flexibility
7. Functional convertibility and flexibility	1. Design for *''function free building''.* 2. Installation of movable walls. 3. Over-dimensioning the size of apartment units. 4. Separation of walls from structure. 5. Provision of a transparent central core. 6. Use Unitized Design.	7. Facilitate Functional Convertibility

8. Technological refit-ability	1. IP backbone and IoT network. 2. Provision of digital twin for tracing the building materials. 3. Leasing Resources (Products as a service).	8. Integrate Technological Refit-Ability
9. Ecological resilience	1. Provision of plants in classrooms. 2. Use Regenerative Design Principles. 3. Consideration of resource-efficient and ecologically-based principles. 4. Share Resources.	9. Promote Ecological Resilience
10. Social and cultural acceptability	1. Empowerment of local entrepreneurs to involve community. 2. Provision of different sizes of apartments / office. 3. Provision of public-accessible courtyards, meeting rooms, working places and rooftop event space. 4. Provision of a multifunctional design. 5. Share Resources.	10. Involve Community in the Building Redevelopment and Use
	6. Preservation of the classical architectural elements to conserve culture. 7. Preservation of monumental parts.	11. Conserve Monumental Elements
11. Biodegradability	1. Providing green roofs or living walls. 2. Use Regenerative Design Principles.	12. Use Biobased Materials
12. Energy renewability and energy efficiency	1. Installation of PVT panels. 2. Installation of PV panels. 3. Use Regenerative Design Principles.	13. Implement Energy Renewability Strategies

5: Enhance Durability of Building Components: Safeguard materials from weather and other external influences, while proactively maintaining them. Increase capacity of different systems through the building design to enhance the buildings long-term resilience. Exemplary solutions for enhancing the building durability are using high-quality façade that meet future acoustical requirements as well as adopting Brand's (1994) *''shearing layers''* concept in the new transformation design. See figure 6 and table 3 for more information about the *''shearing layers''* concept.

6: Provide Configurational Flexibility: Provide shareable spaces with movable walls and adaptable configurations to facilitate and accommodate building changes as per the user needs. Additionally, consider *''products as a service''* to facilitate product exchange, reusability or remanufacturing. See sub-section 3.4.5.8 for more information on *''leasing resources''*.

7: Facilitate Functional Convertibility: Adopt a *"function-free building"* approach in the transformation design by designing spaces that can be easily converted from one function to another. For instance, providing shafts for additional installations and pipelines as well as open floor plan design can facilitate accommodating new functions within the building configuration and altering the building configuration in a flexible manner.

8: Integrate Technological Refit-Ability: Equip the new function with a robust technological infrastructure, using IoT network or leveraging digital twin technologies and Building Information Modeling (BIM) model for material traceability.

9: Promote Ecological Resilience: Implement climate-adaption measures that embody the capacity to withstand heat waves, drought and poor air quality. For instance, consider incorporating green elements such as plants, to contribute to a healthier indoor environment.

10: Involve Community in the Building Redevelopment and Reuse: Assess whether the building can be utilized efficiently and inclusively by sharing the use of spaces and services, thereby operationalizing multiplicity in the use of assets. Design multifunctional spaces with public-accessible areas and different unit sizes emphasizing community involvement for a socially sustainable environment.

11: Conserve Monumental Elements: Preserve monumental parts of the building such as heritage elements, to contribute to cultural acceptability through the adaptive reuse.

12: Use Biobased Materials: Prioritize biodegradability, in order to minimize the environmental impact of building materials and waste generation by considering incorporating features such as green roofs or living walls. This environmental action does not only enhance aesthetic appeal, but also it contributes to a reduction in the dependency on mechanical cooling systems. See sub-section 3.4.4.11 for more information on *''biodegradability''*.

13: Implement Energy Renewability Strategies: Promote the energy renewability by actively providing renewable energy systems, such as PV or PVT panels. Thereby, this would enhance the efficiency of the energy usage in the long-term.

5.2 Validation of the Guidelines

Four interviews were carried out to validate the guidelines. See sub-section 2.3.3 for more information. In each interview, the formulated guidelines were presented to the interviewee to validate the clarity and adequacy of the guidelines. The interviewees reflected on 13 guidelines with some remarks and suggestions. Following are the main remarks on the guidelines:

1: Prioritize Design for Disassembly (DfD): Interviewee D emphasized the importance of detachability.

2: Maximize Material Efficiency: Interviewee D emphasized biobased materials to maximize material efficiency in new assets.

3: Optimize Energy Efficiency: Interviewee D proposed management of collected data.

4: Promote Reusability: Interviewee D proposed mentioning *''leasing resources''* to enable reusability. Interviewee F mentioned that fire safety measures could hinder the reusability because most of the products are wet connections.

5: Enhance Durability of Building Components: Interviewee D emphasized the choice of durable materials.

6: Provide Configurational Flexibility: Interviewee D emphasized the importance of incorporating unitization in designing installations.

7: Facilitate Functional Convertibility: Interviewee D emphasized the importance of daylight entry in floor plan design.

8: Integrate Technological Refit-Ability: Interviewee D emphasized the importance of material passports.

9: Promote Ecological Resilience: Interviewee D emphasized the context of the building, water buffers and biodiversity.

10: Involve Community in the Building Redevelopment and Use: Interviewee D emphasized the importance of mixing daytime and night-time activities in building use.

11: Conserve Monumental Elements: Interviewee A emphasized preserving characteristic building parts.

12: Use Biobased Materials: Interviewee F mentioned that fire safety measures could hinder the use of biobased materials such as biobased insulation contain plastic for fire safety regulations.

13: Implement Energy Renewability Strategies: Interviewee A emphasized the importance of aligning energy renewability strategies between building and area scale level.

5.3 Final Version of the Guidelines

The feedback were reported and discussed with another researcher as a secondary source for data triangulation. Therefore, the guidelines were revised:

1: Prioritize Design for Disassembly (DfD): Standardize construction elements in terms of their connections and dimensions to facilitate replaceability, detachability and accessibility, while avoiding unnecessary overlap of diverse building components and elements. Thereby, this will embody adaptability for future adjustments, particularly fostering circularity and longevity. Figure 9 illustrates the possible measures to facilitate DfD in building transformation.

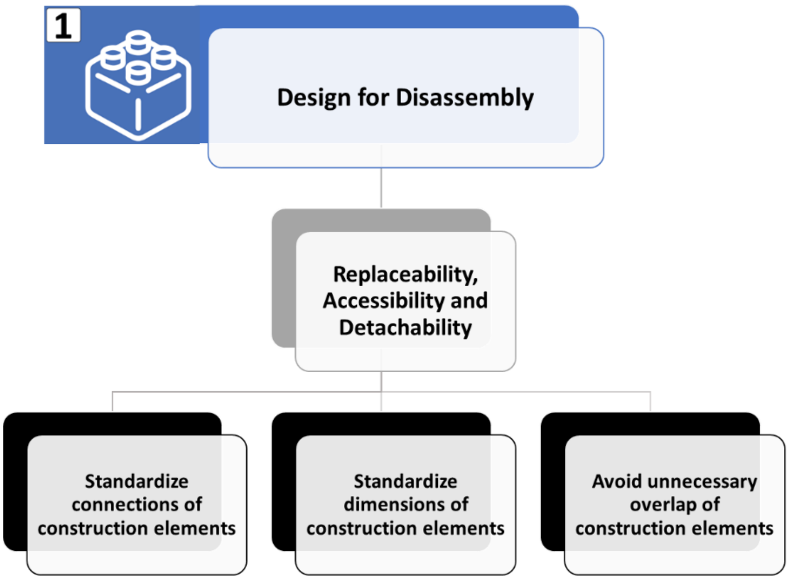

Figure 9: Possible measures to facilitate DfD in building transformation. (Source: own illustration, 2024)

2: Maximize Material Efficiency: Minimize the use of new material by reusing existing components and repairing deteriorated elements. Additionally, other material reprocessing measures may include repurposing and renovating building assets. For new building assets, using recycled materials, second-hand products and considering biobased materials can be implemented to maximize material efficiency as well as foster the reusability of assets in the long-term. Figure 10 illustrates the possible measures for maximizing material efficiency in building transformations.

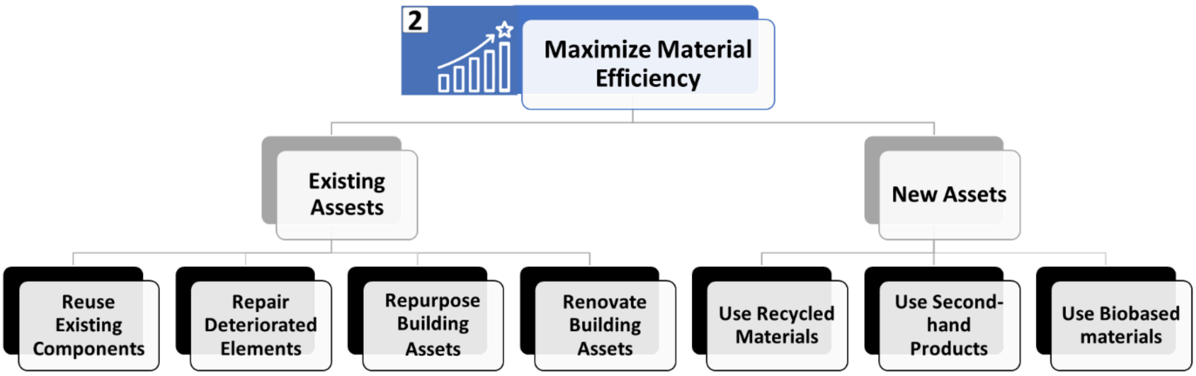

Figure 10: Possible measures for maximizing material efficiency in building transformations. (Source: own illustration, 2024)

3: Optimize Energy Efficiency: Enhance the energy use and management in the building by installing smart building technologies, such as sensors and data collection systems, that monitor energy efficiency. Additionally, consider the management of the collected data for optimization of energy use. Other systems can encompass motion-tracking sensors and LED lighting, which reduce energy consumption in unoccupied spaces. Figure 11 illustrates the possible measures for optimizing energy efficiency in building transformations.

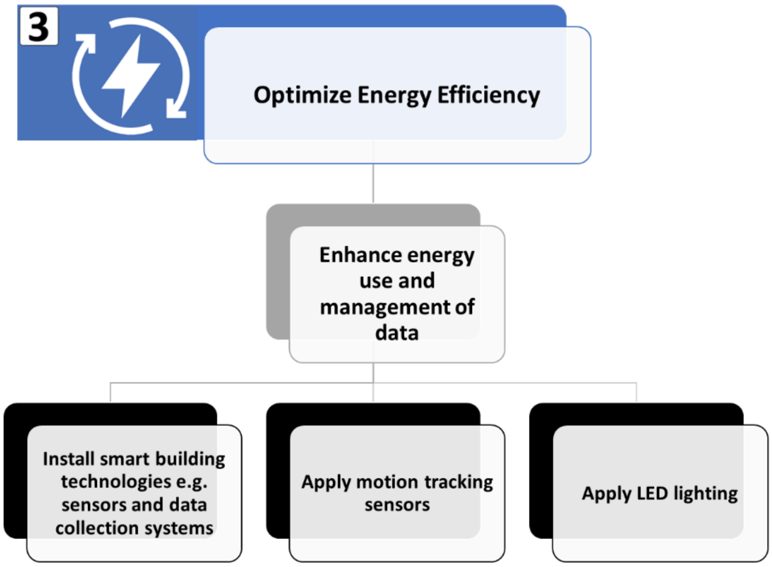

Figure 11: Possible measures for optimizing energy efficiency in building transformations. (Source: own illustration, 2024)

4: Promote Reusability: For existing assets, restore old building components and systems. For new assets, utilize standardized and modular building components and elements in terms of measurement, and items in order to facilitate their reuse afterwards. For existing and new assets, consider installing components elements and systems using dry connections. Also, *''leasing resources''* to promote their reusability and maintenance afterwards. Thereby, this will enhance the efficiency of material usage in the long-term. All of these options should satisfy the fire safety requirements of the new building use. Figure 12 illustrates the possible measures for promoting reusability in building transformations.

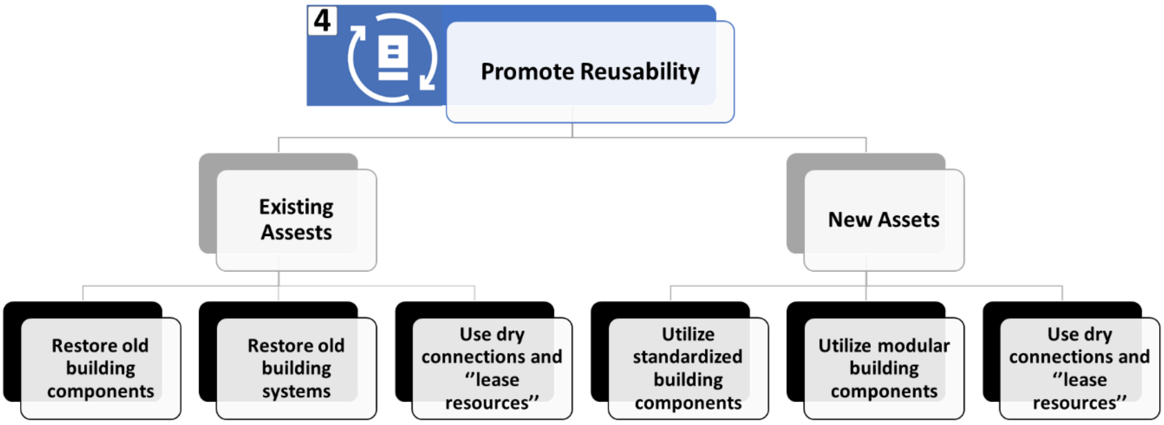

Figure 12: Possible measures for promoting reusability in building transformations. (Source: own illustration, 2024)

5: Enhance Durability of Building Components: Safeguard materials from weather and other external influences, while proactively maintaining them and consider choosing durable materials. Increase capacity of different systems through the building design to enhance the buildings long-term resilience. Exemplary solutions for enhancing the building durability are using high-quality façade that meet future acoustical requirements as well as adopting Brand's (1994) *''shearing layers''* concept in the new transformation design. See figure 6 and table 3 for more information about the *''shearing layers''* concept. Figure 13 illustrates the possible measures for enhancing durability in building transformations.

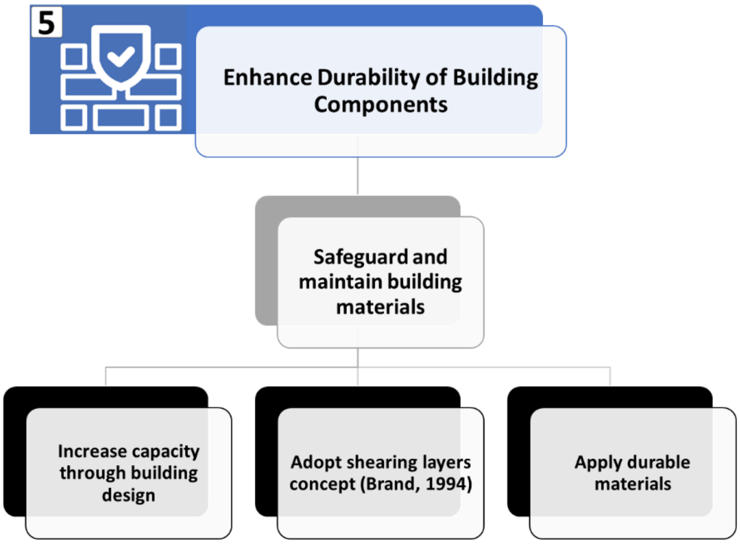

Figure 13: Possible measures for enhancing durability in building transformations. (Source: own illustration, 2024)

6: Provide Configurational Flexibility: Provide shareable spaces with movable walls and adaptable configurations to facilitate and accommodate building changes as per the user needs. Additionally, consider *''products as a service'' or ''leasing resources''* to facilitate product exchange or remanufacturing. Unitized asset dimensions and installations play a pivotal role in providing configurational flexibility. Thereby, this will foster reusability of assets in the long-term. See sub-section 3.4.5.8 for more information on *''leasing resources''*. Thereby, this will foster reusability of assets in the long-term. Figure 14 illustrates the possible measures for providing configurational flexibility in building transformations.

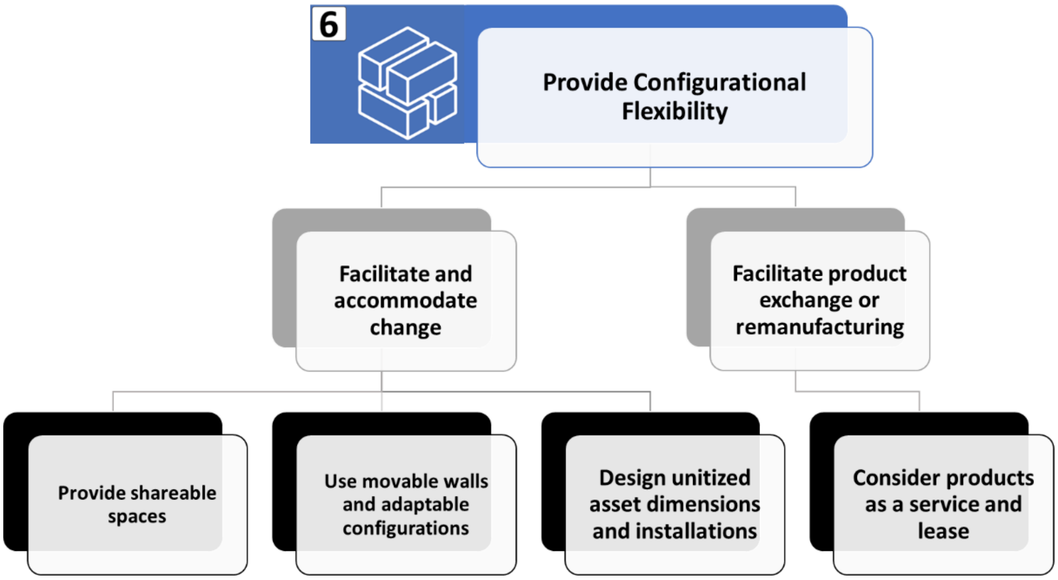

Figure 14: Possible measures for providing configurational flexibility in building transformations. (Source: own illustration, 2024)

7: Facilitate Functional Convertibility: Adopt a *"function-free building"* approach in the transformation design by designing spaces that can be easily converted from one function to another. For instance, providing shafts for additional installations and pipelines as well as open floor plan design can facilitate accommodating new functions within the building configuration. Furthermore, daylight need to be facilitated in the new transformation design to facilitate the building convertibility to another functions. Therefore, this will embody the flexibility for future adjustments of assets in the long-term. Figure 15 illustrates the possible measures for facilitating functional convertibility in building transformations.

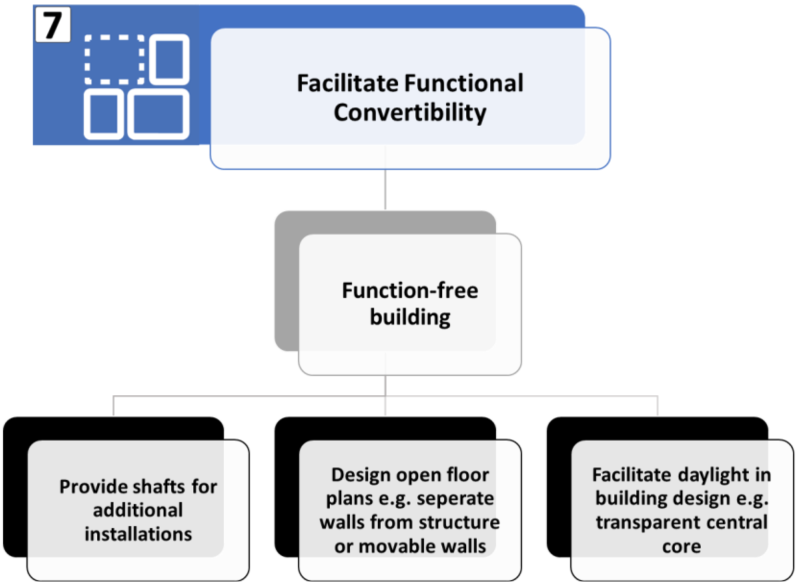

Figure 15: Possible measures for facilitating functional convertibility in building transformations. (Source: own illustration, 2024)

8: Integrate Technological Refit-Ability: Equip the new function with a robust technological infrastructure, using IoT networks or leveraging digital twin technologies and Building Information Modeling (BIM) models for material traceability and consider material passports. Figure 16 illustrates the possible measures for integrating technological refit-ability in building transformations.

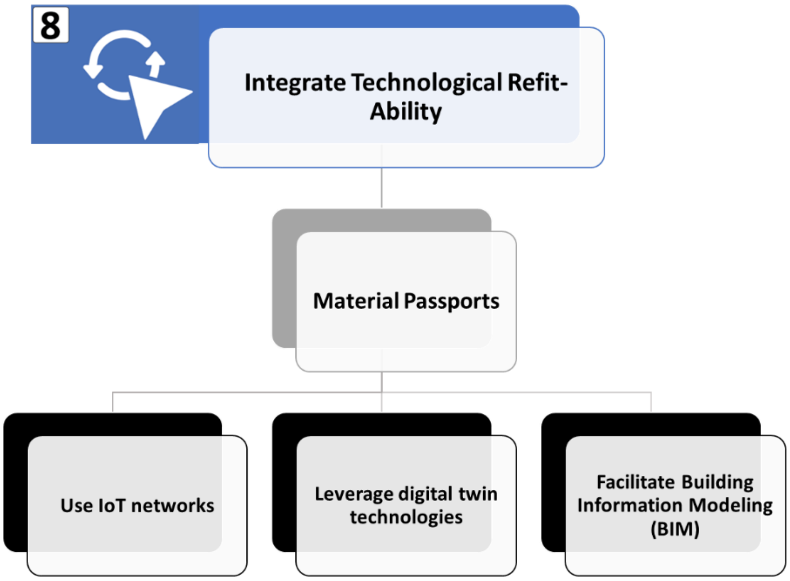

Figure 16: Possible measures for integrating technological refit-ability in building transformations. (Source: own illustration, 2024)

9: Promote Ecological Resilience: Implement climate-adaption measures that embody the capacity to withstand heat waves, drought, and poor air quality. For instance, consider incorporating green elements such as plants to contribute to a healthier indoor environment. Additionally, consider the biodiversity in the context of the building by the means of applying the so-called water buffers. Figure 17 illustrates the possible measures for promoting ecological resilience in building transformations..

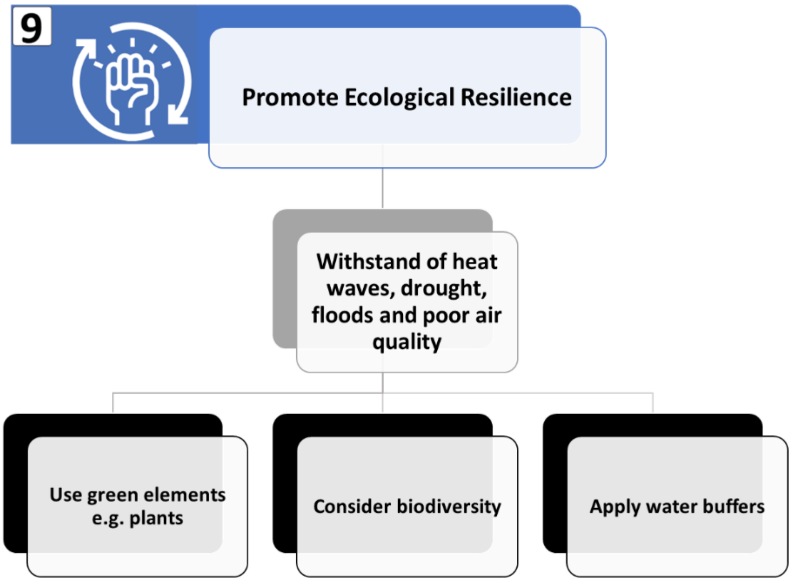

Figure 17: Possible measures for promoting ecological resilience in building transformations. (Source: own illustration, 2024)

10: Involve Community in the Building Redevelopment and Use: Assess whether the building can be utilized efficiently and inclusively by sharing the use of spaces and services, thereby operationalizing multiplicity in the use of assets day and night. Design multifunctional spaces with public-accessible areas and different unit sizes emphasizing community involvement for a socially sustainable environment. Figure 18 illustrates the possible measures for involving community in building transformations.

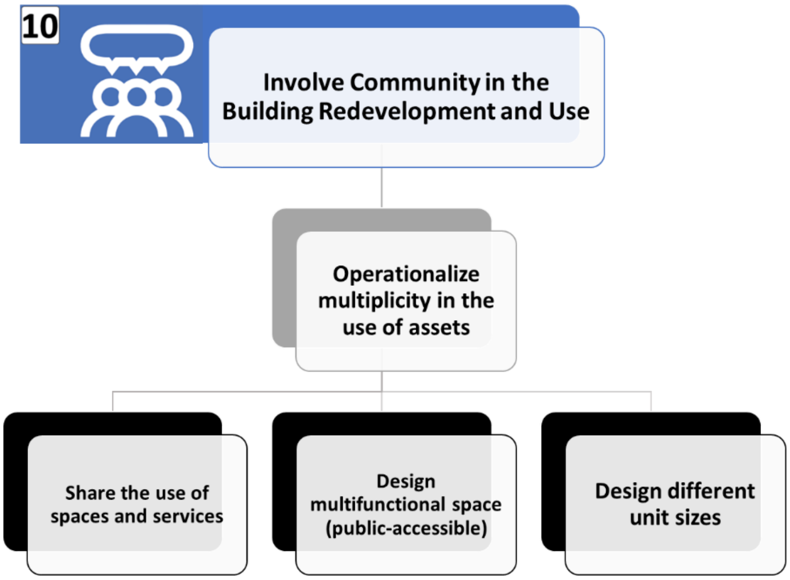

Figure 18: Possible measures for involving community in building transformations. (Source: own illustration, 2024)

11: Conserve Monumental Elements: Preserve monumental or characteristic parts of the building such as heritage elements, to contribute to cultural acceptability through the adaptive reuse. Figure 19 illustrates the possible measures for conserving monumental elements in building transformations

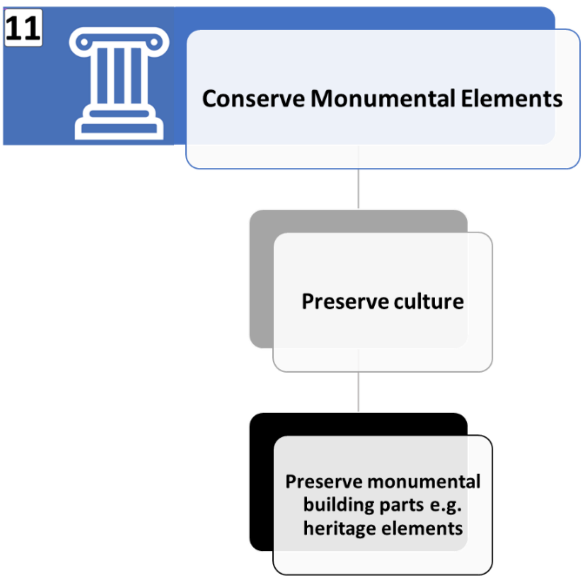

Figure 19: Possible measures for conserving monumental elements in building transformations. (Source: own illustration, 2024)

12: Use Biobased Materials: Prioritize biodegradability to minimize the environmental impact of building materials and waste generation by considering incorporating features like green roofs or living walls, which not only enhance aesthetic appeal but also contribute to a reduction in the dependency on mechanical cooling systems. All of these options should satisfy the fire safety requirements of the new building use. Figure 20 illustrates the possible measures for using biobased materials in building transformations. See sub-section 3.4.4.11 for more information on *''biodegradability''*.

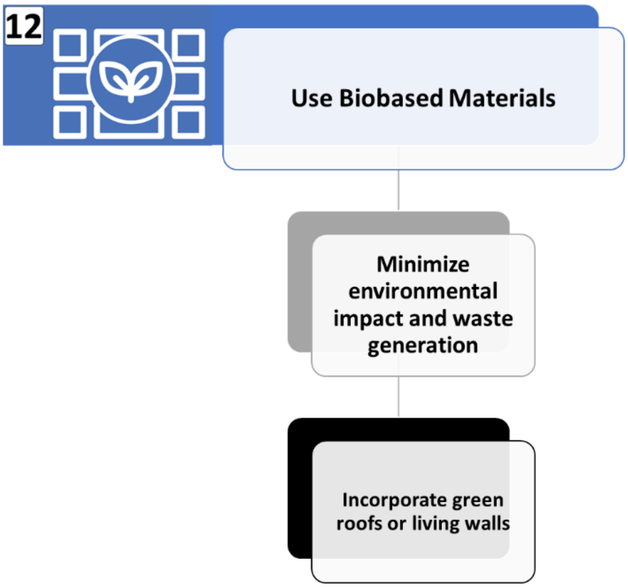

Figure 20: Possible measures for using biobased materials in building transformations. (Source: own illustration, 2024)

13: Implement Energy Renewability Strategies: Promote the energy renewability by actively providing renewable energy systems, such as PV or PVT panels and smart storage of energy. Additionally, consider these measures on building scale and area scale level. Figure 21 illustrates the possible measures for implementing energy renewability in building transformations.

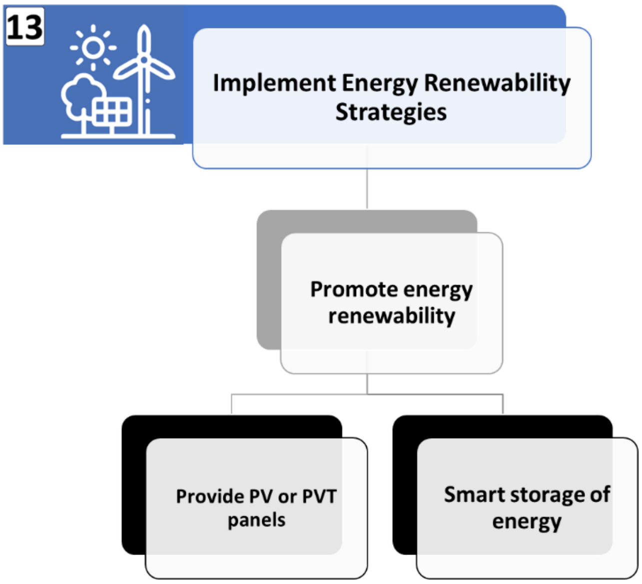

Figure 21: Possible measures for implementing energy renewability in building transformations. (Source: own illustration, 2024)

5.4 Conclusion

This chapter covered a development and validation of practical guidelines for promoting circularity and adaptability in the transformation of vacant and obsolete buildings. According to the identified criteria and measures from the literature and case studies, 13 guidelines were formulated and mapped to the corresponding criteria. The findings of the carried out validation indicate that these guidelines are generally clear, adequate and usable by professionals as a guiding tool to foster CBA in the adaptive reuse of obsolete and vacant buildings. In conclusion, reviewing the guidelines through interviews with other researchers facilitates further development of applicable guidelines. Further improvements can be made by interviewing policy makers to align guidelines with regulations, legislation and rules.

6. Chapter 6: Conclusions, recommendations and limitations

6.1 Overview

There is a misunderstanding of the promotion of building adaptability in building transformation in terms of its utility as a means and main requirement to convert obsolete real estate in a resource-efficient and future-proof manner. It is worth noting that many constructed buildings lack for adaptability to accommodating future changes and reducing waste generation owing to a focus on immediate societal needs with an overlooking of future needs and dynamics. This necessitates the development of a guiding tool for stakeholders and practitioners involved in the circular and adaptable reuse of less functioning built assets. This chapter includes the answers to the main research question – How can circularity and adaptability be promoted in the reuse of vacant and obsolete real estate? –,: recommendations, and research limitations.

6.2 Conclusions

To answer the aforementioned research question, three research sub-questions were inquired and tackled, namely:

1: *"What are the criteria and measures for reusing obsolete and vacant building in a circular and adaptable manner?"*

2: *''To what extent are circularity- and adaptability- related measures implemented in reusing vacant and obsolete buildings?''*

3: *''How can guidelines guide professionals on how to promote circularity and adaptability related measures in the reuse of vacant and obsolete buildings?''*

To answer these sub-questions, three approaches were followed sequentially in this research, namely: *''Documentation of existing knowledge.''; ''Case studies on circular adaptive reuse projects of vacant and obsolete buildings.''; and ''Formulation and validation of guidelines based on knowledge gained from theory and practice.''*

The literature review, the first approach, thoroughly explored interrelated concepts, namely building obsolescence, building vacancy, adaptive reuse, adaptability, and circularity and circularity in the built environment. To precisely answer the first research sub-question and pave the way for the empirical part of this research, the literature review concluded with an identification of 12 practical criteria and 8 measures for circular and adaptable reuse of vacant and obsolete buildings. The 12 criteria include *"design for disassembly", "material efficiency", "energy efficiency", "reusability", "durability", "flexibility", "functional convertibility", "technological refit-ability", "ecological resilience", "social and cultural acceptability", "biodegradability" and "energy renewability"*. The 8 measures are: *"use material passports", "use recycled materials", "use dismantlable design", "use unitized design", "use digital technologies", "use regenerative design principles", "share resources" and "leasing resources"*.

In the followed qualitative case study approach, archival research, in-depth interviews and field observations were used as primary data collection techniques to reveal to what extent circularity- and adaptability- related measures are implemented in reusing vacant and obsolete assets in two case studies. The first case study involved the conversion of a partially vacant and obsolete office building into a function-free-mixed-use property with an anticipated completion in autumn 2024. The second case study focused on the redevelopment of 10 vacant office towers with 7 towers repurposed as mixed-use towers while the remaining 3 transformed into an international school. The cross-case analysis pointed out a heterogeneity and some similarities in the application of specific circular and adaptable adaptive reuse measures in two cases. For instance, the *"use of unitized design"* and *"reuse of old building products and components"* were applied across both cases, showing a consistent integration of reusable building products and components in the building transformation. In addition, *''use recycled materials''* was not applied in both cases, although this measure showed an interconnection with two criteria, namely *''material efficiency''* and *''reusability''*. Furthermore, the application of environment-oriented measures that promote *"biodegradability"* and *"ecological resilience"* were barely applied in the two cases. Two other measures, namely *''use material passports''* and *''leasing resources'',* from the literature were not implemented in both cases as well. The cross-case analysis pointed out that there are eight new measures applied in practice and not explicitly mentioned in the literature, namely: *''design for excess capacity", "reuse of old building products and components", "preserving cultural elements", "community involvement in the development process", "adoption of green design principles", "optimization of resource utilization", "elimination of waste" and "use of energy efficient lighting/ventilation''*. However, *''durability''* was only in case 1, while *''ecological resilience''* was implemented only in case 2.

Based on the knowledge gained from the theory and practice, in the third approach, 13 guidelines were formulated and mapped to the relevant criteria. These guidelines have been validated and revised based on four structured interviews. The 13 guidelines were refined to cover the following themes: *''prioritize design for disassembly", "maximize material efficiency", "optimize energy efficiency", "promote reusability", "enhance durability of building components", "provide configurational flexibility", "facilitate functional convertibility", "integrate technological refit-ability", "promote ecological resilience", "involve community in the building redevelopment and reuse", "conserve monumental elements", "use biobased materials" and "implement energy renewability strategies''*. By integrating these guidelines into their practices, architects, engineers, and contractors (AECs) as well as building managers can ensure that their strategies align with the broader goals of the circular economy. And thereby, answer the main research question of this thesis.

6.3 Recommendations

Based on the conclusion of this study, the following recommendations have been proposed:

- Future research can involve testing the guidelines and learn from practice to enhance the effectiveness and applicability of them in practice.
- Policy makers can further consult researchers and practitioners to include the latest knowledge with the aim of amending existing legislation to facilitate a circular economy.
- To enhance the accessibility of the guidelines, it is recommended to develop a web application. The web application should enable the content to be presented in an interactive manner, taking into consideration the visual orientation of designers and prioritization of the guidelines in different contexts.
- Building professionals should consider and further promote environment-oriented criteria, such as *"biodegradability"* by using recycled material and/or using regenerative design principles. Also, *"ecological resilience"* by using regenerative design principles and/or sharing resources.

6.4 Limitations

This research has several limitations:

- The empirical evidence was limited to only two case studies.
- The guidelines were formulated based on interpretations of the literature and findings of two case studies. Different researchers or practitioners may have different interpretations, leading to potential subjectivity in the development of guidelines.
- The incorporated measures into the guidelines and the guidelines themselves were not prioritized in terms of their significance.
- The guidelines were validated in terms of their adequacy, clarity and usability, but have not been tested in practice nor in a pilot application.

7. Chapter 7: Reflection

Let me start by answering the question why I conducted this research. The main reason for choosing to research a solution for enormous vacancy and obsolescence that we are facing in our office market in the Netherlands. As a starting engineer, I believe that it should not be the case that we create buildings that are not futureproof, and not efficient in terms of energy and materials. Adaptive reuse is seen as a promising solution for coping with growing number of vacant buildings in the Netherlands. Currently, researchers began delving into this matter within the principles of circular economy. One notable researcher, Mohammad Hamida, drew my attention through aligning adaptive reuse with principles of circular economy and adaptability as a means to resource-efficient and futureproof redevelopment. Motivated by this, I teamed up with Mohammad (second mentor) and Professor Hans Wamelink (first mentor) who was the chair of CB23, a platform publishing guidelines for circular building design and construction. With their expertise I was assured to research the subject in this thesis. Additionally, I have been working at NEN for many years, the Dutch institute for the development of standards and guiding tools, which also influenced my choice because they are currently developing guidelines for circular building design together with CB23.

Throughout my thesis, I adopted three distinct approaches: understanding circularity and adaptive reuse theory, assessing real-world applications, and formulating practical guidelines by combining theoretical knowledge and real-world insights. The practicality and validity of these guidelines were pursued through a continuous feedback loop involving my mentors and practitioners.

The significance of this research lies in addressing the need for a circular economy, vital for the planet. Selecting mentors with experience in circular design and working on relevant case studies contributed to the creation of meaningful knowledge. The ongoing process of refining conclusions, recommendations, and limitations, as well as formulating and validating guidelines, will continue until P5.

Regarding the relation to my master track (management in the built environment) and master program (MSc AUBS), my graduation project aligns with the societal need of fostering a circular economy, particularly within the built environment as a huge producer of waste.

Reflecting on the research's influence on my design and recommendations, it has contributed to raising my awareness of the importance of promoting circularity in building design. I think that this perspective will permanently shape my approach to designing, promoting circular solutions for speeding up the transition to a circular built environment.

The value of my approach and methodology is enhanced by the involvement of mentors actively contributing to the development of guidelines in their career. The academic and societal value of my project lies in its contribution to coping with the surplus vacancy and obsolescence in the existing building stock, with ethical considerations focused on learning from past mistakes to guide future developments responsibly.

The way I communicate the results is apparently understandable for professionals in the building industry. It contains a lot of knowledge from the built environment and will be understandable for people who are not familiar with designing buildings.

Along the way, I realized that the solutions I was thinking about were experienced as important by fellow peers, other researchers and my colleagues in my profession. Because of this, everyone was always willing to contribute to the research because it's such a growing topic in society. I would advise every student to choose a topic that is relevant to the society. This willingness of people to help me, gave me satisfaction and I would even like to continue with this research, also really improve the quality of the outcomes. What I would do differently is spend full time in my graduation project towards deep understanding of the subject, however, due to other commitments this was not possible.

References

Akadiri, P. O., Chinyio, E. A., & Olomolaiye, P. O. (2012). Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. *Buildings*, *2*(2), 126–152. https://doi.org/10.3390/buildings2020126

Akhimien, N. G., Latif, E., & Hou, S. S. (2021). Application of circular economy principles in buildings: A systematic review. *Journal of Building Engineering*, *38*(m). https://doi.org/10.1016/j.jobe.2020.102041

Andersen, R., Jensen, L. B., & Ryberg, M. W. (2022). Adaptation of circular design strategies based on historical trends and demolition patterns. *IOP Conference Series: Earth and Environmental Science*, *1085*(1), 64DUMMY. https://doi.org/10.1088/1755-1315/1085/1/012062

Andrade, J., Araújo, C., Castro, M. F., & Bragana, L. (2019). New Methods for Sustainable Circular Buildings. *IOP Conference Series: Earth and Environmental Science*, *225*(1). https://doi.org/10.1088/1755-1315/225/1/012037

Antonini, E., Boeri, A., Lauria, M., & Giglio, F. (2020). Reversibility and durability as potential indicators for circular building technologies. *Sustainability (Switzerland)*, *12*(18). https://doi.org/10.3390/su12187659

Antwi-Afari, P., Ng, S. T., & Chen, J. (2022). Developing an integrative method and design guidelines for achieving systemic circularity in the construction industry. *Journal of Cleaner Production*, *354*(December 2021), 131752. https://doi.org/10.1016/j.jclepro.2022.131752

Armstrong, G., Soebarto, V., & Zuo, J. (2021). Vacancy Visual Analytics Method: Evaluating adaptive reuse as an urban regeneration strategy through understanding vacancy. *Cities*, *115*(July 2020), 103220. https://doi.org/10.1016/j.cities.2021.103220

Armstrong, G., Wilkinson, S. J., & Cilliers, E. J. (2021). *Sustainable Temporary Adaptive Reuse for a COVID-19 Recovery and Resilient Cities Approach Sustainable Temporary Adaptive Reuse for a COVID-19 Recovery and Resilient Cities Approach*. (December).

ARUP. (2016). The Circular Economy in the Built Environment. *Callifornia Academy of Sciences, San Francisco, USA*, 1–93.

ARUP, & Ellen MacArthur Foundation. (2018). *From principles to practices: First steps towards a circular built environment*.

ARUP, & Ellen MacArthur Foundation. (2020). *From Principles to Practices: Realising the value of circular economy in real estate*. 106.

Askar, R., Bragança, L., & Gervásio, H. (2021). Adaptability of buildings: A critical review on the concept evolution. *Applied Sciences (Switzerland)*, *11*(10). https://doi.org/10.3390/app11104483

Askar, R., Bragança, L., & Gervásio, H. (2022). Design for Adaptability (DfA)—Frameworks and Assessment Models for Enhanced Circularity in Buildings. *Applied System Innovation*, *5*(1), 1–25. https://doi.org/10.3390/asi5010024

Atta, I., Bakhoum, E. S., & Marzouk, M. M. (2021). Digitizing material passport for sustainable construction projects using BIM. *Journal of Building Engineering*, *43*(June), 103233. https://doi.org/10.1016/j.jobe.2021.103233

Azcárate-Aguerre, J. F. (2023). *Facades-as-a-Service* (23#11). https://doi.org/https://doi.org/10.7480/abe.2023.11

Bajaj, D., Depuy, L., Devine, B., Dewulf, G., Ding, G., Drogemuller, R., … Wilkinson, S. (2011). *Workplace Strategies and Facilities Management: Building in Value* (R. Best, C. Langston, & G. de Valence, eds.). Milton Park, Abingdon-on-Thames, Oxfordshire, England, UK: Spon Press.

Baum, A., & Hartzell, D. . (1997). The Causes and Effects of Depreciation in Office Buildings : a Ten Year Update The Causes and Effects of Depreciation in Office Buildings : a Ten Year Update. *4th European Real Estate Society Conference (ERES)*.

Beadle, K., Gibb, A., Austin, S., Fuster, A., & Madden, P. (2008). Adaptable futures: Sustainable aspects of adaptable buildings. *Association of Researchers in Construction Management,*

ARCOM 2008 - Proceedings of the 24th Annual Conference, *2*(October 2014), 1125–1134.
Bertino, G., Kisser, J., Zeilinger, J., Langergraber, G., Fischer, T., & Österreicher, D. (2021). Fundamentals of building deconstruction as a circular economy strategy for the reuse of construction materials. *Applied Sciences (Switzerland)*, *11*(3), 1–31. https://doi.org/10.3390/app11030939
Brand, S. (1994). *How Buildings Learn: What Happens After They're Built*. Viking Press.
Calheiros, C. S. C., & Stefanakis, A. I. (2021). Green Roofs Towards Circular and Resilient Cities. *Circular Economy and Sustainability*, *1*(1), 395–411. https://doi.org/10.1007/s43615-021-00033-0
Cambier, C., Galle, W., & De Temmerman, N. (2020). Support Tools for Circular Building. *Buildings*, 1–20.
Caves, R. W. (2005). Encyclopedia of the City. *Taylor & Francis Group*, *Routledge*, 626. https://doi.org/https://doi.org/10.4324/9780203484234
Cerreta, M., Elefante, A., & La Rocca, L. (2020). A creative living lab for the adaptive reuse of the morticelli church: The ssmoll project. *Sustainability (Switzerland)*, *12*(24), 1–20. https://doi.org/10.3390/su122410561
Çetin, S., De Wolf, C., & Bocken, N. (2021). Circular digital built environment: An emerging framework. *Sustainability (Switzerland)*, *13*(11). https://doi.org/10.3390/su13116348
Çetin, S., Gruis, V., & Straub, A. (2021). Towards circular social housing: An exploration of practices, barriers, and enablers. *Sustainability (Switzerland)*, *13*(4), 1–24. https://doi.org/10.3390/su13042100
Çetin, S., Gruis, V., & Straub, A. (2022). Digitalization for a circular economy in the building industry: Multiple-case study of Dutch social housing organizations. *Resources, Conservation and Recycling Advances*, *15*(August), 200110. https://doi.org/10.1016/j.rcradv.2022.200110
Dams, B., Maskell, D., Shea, A., Allen, S., Driesser, M., Kretschmann, T., … Emmitt, S. (2021). A circular construction evaluation framework to promote designing for disassembly and adaptability. *Journal of Cleaner Production*, *316*(October 2020), 128122. https://doi.org/10.1016/j.jclepro.2021.128122
Dewagoda, K. G., Thomas Ng, S., & Kumaraswamy, M. M. (2022). Design for Circularity: The Case of the Building Construction Industry. *IOP Conference Series: Earth and Environmental Science*, *1101*(6). https://doi.org/10.1088/1755-1315/1101/6/062026
Eberhardt, L. C. M., Birkved, M., & Birgisdottir, H. (2022). Building design and construction strategies for a circular economy. *Architectural Engineering and Design Management*, *18*(2), 93–113. https://doi.org/10.1080/17452007.2020.1781588
Eliote, G., & Leite, F. (2022). Towards Circular Economy in the Built Environment: Overcoming Obsolescence via Building Adaptation. *University of Texas at Austin*, *Architectu*(Construction Engineering and Project Management Program, Department of Civil), 22.
Foster, G. (2020). Circular economy strategies for adaptive reuse of cultural heritage buildings to reduce environmental impacts. *Resources, Conservation and Recycling*, *152*(October 2019), 104507. https://doi.org/10.1016/j.resconrec.2019.104507
Fox, S., Marsh, L., & Cockerham, G. (2002). Constructability rules: Guidelines for successful application to bespoke buildings. *Construction Management and Economics*, *20*(8), 689–696. https://doi.org/10.1080/01446190210163606
Garcia, E. J. (2022). Ecological Resilience and the Built Environment. *The Palgrave Handbook of Climate Resilient Societies: Volumes 1-2*, *1*, 883–901. https://doi.org/10.1007/978-3-030-42462-6_78
Geldermans, B., Tenpierik, M., & Luscuere, P. (2019). Circular and flexible infill concepts: Integration of the residential user perspective. *Sustainability (Switzerland)*, *11*(1). https://doi.org/10.3390/su11010261
Geldermans, R. J. (2016). Design for Change and Circularity - Accommodating Circular Material & Product Flows in Construction. *Energy Procedia*, *96*(October), 301–311.

https://doi.org/10.1016/j.egypro.2016.09.153
Ghufran, M., Iqbal, K., Khan, A., Ullah, F., Nasir, A. R., Aziz, A., … Alwetaishi, M. (2022). Circular Economy in the Construction Industry : A Step towards Sustainable Development. *Buildings*, *12*, 1004.
Gibbons, L. V. (2020). Regenerative — The New Sustainable ? *Scientific Research on Sustainable Development Goals*, *12*(13), 1–19. https://doi.org/https://doi.org/10.3390/su12135483
Girard, L. F. (2020). The circular economy in transforming a died heritage site into a living ecosystem, to be managed as a complex adaptive organism. *Aestimum*, *77*, 145–180. https://doi.org/10.13128/aestim-9788
Hamida, M. B., & Hassanain, M. A. (2021). Investigation of AEC/FM practices in adaptive reuse projects. *International Journal of Building Pathology and Adaptation*. https://doi.org/10.1108/IJBPA-12-2020-0106
Hamida, M. B., & Hassanain, M. A. (2022). A framework model for AEC/FM knowledge in adaptive reuse projects. *Journal of Engineering, Design and Technology*, *20*(3), 624–648. https://doi.org/10.1108/JEDT-05-2020-0203
Hamida, M. B., & Hassanain, M. A. (2023). AEC/FM performance in adaptive reuse projects: Investigation of challenges and development of practical guidelines. *Facilities*, 31.
Hamida, M. B., Jylhä, T., Remøy, H., & Gruis, V. (2022). Circular building adaptability and its determinants – A literature review. *International Journal of Building Pathology and Adaptation*. https://doi.org/10.1108/IJBPA-11-2021-0150
Hamida, M. B., Remøy, H., Gruis, V., & Jylhä, T. (2023). Circular building adaptability in adaptive reuse: multiple case studies in the Netherlands. *Journal of Engineering, Design and Technology*. https://doi.org/10.1108/JEDT-08-2022-0428
Harputlugil, T., & de Wilde, P. (2021). The interaction between humans and buildings for energy efficiency: A critical review. *Energy Research and Social Science*, *71*(October 2020), 101828. https://doi.org/10.1016/j.erss.2020.101828
Hassanain, M. A. (2005). Guidelines for the Design of Water and Sewage Systems in Buildings. *Journal of Architectural Engineering*, *11*(4), 117–121. https://doi.org/10.1061/(asce)1076-0431(2005)11:4(117)
Hassanain, M. A., Sanni-Anibire, M. O., Mahmoud, A. S., & Hamida, M. B. (2020). Design guidelines for the functional efficiency of laboratory facilities. *Architectural Engineering and Design Management*, *16*(2), 115–130. https://doi.org/10.1080/17452007.2019.1675580
Heidrich, O., Kamara, J., Maltese, S., Re Cecconi, F., & Dejaco, M. C. (2017). A critical review of the developments in building adaptability. *International Journal of Building Pathology and Adaptation*, *35*(4), 284–303. https://doi.org/10.1108/IJBPA-03-2017-0018
Hennink, M., Hutter, I., & Bailey, A. (2011). Chapter 6: In-Depth Interviews. In *Qualitative Research Methods* (pp. 108 – 131). London, UK: SAGE Publications Ltd.
Ikiz Kaya, D., Dane, G., Pintossi, N., & Koot, C. A. M. (2021). Subjective circularity performance analysis of adaptive heritage reuse practices in the Netherlands. *Sustainable Cities and Society*, *70*(December 2020), 102869. https://doi.org/10.1016/j.scs.2021.102869
Ikiz Kaya, D., Lu, L., Pintossi, N., & Pereira Roders, A. (2021). Operationalising the HUL tools at Building Level: Circular Models of Adaptive Reuse. *LDE Heritage Conference on Heritage and the Sustainable Development Goals: Proceedings*, 315–324.
Insuranceopedia. (2018). Vacant Building. Retrieved October 25, 2022, from www.insuranceopedia.com website: https://www.insuranceopedia.com/definition/537/vacant-building#:~:text=A vacant building is a,relevant for property insurance coverage.
Iselin, D. G., & Lemer, A. C. (1993). *The Fourth Dimension in Building: Strategies for Obsolescence Committee on Facility Design To Minimize*. Washington, D.C., USA: National Academy Press.
Iyer-Raniga, U. (2019). Using the ReSOLVE framework for circularity in the building and construction industry in emerging markets. *IOP Conference Series: Earth and Environmental Science*, *294*(1).

https://doi.org/10.1088/1755-1315/294/1/012002
Kamara, J. M., Heidrich, O., Tafaro, V. E., Maltese, S., Dejaco, M. C., & Re Cecconi, F. (2020). Change factors and the adaptability of buildings. *Sustainability (Switzerland)*, *12*(16). https://doi.org/10.3390/su12166585
Kanters, J. (2020). Circular building design: An analysis of barriers and drivers for a circular building sector. *Buildings*, *10*(4), 1–16. https://doi.org/10.3390/BUILDINGS10040077
Khadim, N., Agliata, R., Marino, A., Thaheem, M. J., & Mollo, L. (2022). Critical review of nano and micro-level building circularity indicators and frameworks. *Journal of Cleaner Production*, *357*(October 2021), 131859. https://doi.org/10.1016/j.jclepro.2022.131859
Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*(September), 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005
Kitagorsky, J. (2022). A Concept for Sustainable Building Projects Using Hybrid Modular and Adaptive Reuse Strategies By. *A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering*, (THE COOPER UNION FOR THE ADVANCEMENT OF SCIENCE AND ART ALBERT NERKEN SCHOOL OF ENGINEERING), 118.
Langston, C., & Conejos, S. (2014). Designing for Future Adaptive Reuse. *Sustainable Building Adaptation: Innovations in Decision-Making*, *9781118477*(December 2010), 250–272. https://doi.org/10.1002/9781118477151.ch12
Langston, C., Wong, F. K. W., Hui, E. C. M., & Shen, L. Y. (2008). Strategic assessment of building adaptive reuse opportunities in Hong Kong. *Building and Environment*, *43*(10), 1709–1718. https://doi.org/10.1016/j.buildenv.2007.10.017
Minunno, R., O'Grady, T., Morrison, G. M., Gruner, R. L., & Colling, M. (2018). Strategies for applying the circular economy to prefabricated buildings. *Buildings*, *8*(9). https://doi.org/10.3390/buildings8090125
Munaro, M. R., Tavares, S. F., & Bragança, L. (2020). Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. *Journal of Cleaner Production*, *260*. https://doi.org/10.1016/j.jclepro.2020.121134
Ness, D. A., & Xing, K. (2017). Toward a Resource-Efficient Built Environment: A Literature Review and Conceptual Model. *Journal of Industrial Ecology*, *21*(3), 572–592. https://doi.org/10.1111/jiec.12586
Owojori, O. M., & Okoro, C. (2022). *Making the ' Available Desirable ' Using Adaptive Reuse (AR) In Sustainable Construction : A Systematic Review and Directions from case studies*. (October).
Owojori, O. M., Okoro, C. S., & Chileshe, N. (2021). Current status and emerging trends on the adaptive reuse of buildings: A bibliometric analysis. *Sustainability (Switzerland)*, *13*(21). https://doi.org/10.3390/su132111646
Park, I., & Hannafin, M. J. (1993). Empirically-Based Guidelines for the Design of Interactive Multimedia. *Educational Technology Research & Development*, *4*(3), 63–85.
Pinder, J. A., Schmidt, R., Austin, S. A., Gibb, A., & Saker, J. (2017). What is meant by adaptability in buildings? *Facilities*, *35*(1–2), 2–20. https://doi.org/10.1108/F-07-2015-0053
Ping Tserng, H., Chou, C. M., & Chang, Y. T. (2021). The key strategies to implement circular economy in building projects-a case study of Taiwan. *Sustainability (Switzerland)*, *13*(2), 1–17. https://doi.org/10.3390/su13020754
Platform CB'23. (2021). *Circulair ontwerpen*. 18–35.
Ploeger, H., Prins, M., Straub, A., & Van den Brink, R. (2019). Circular economy and real estate: the legal (im)possibilities of operational lease. *Facilities*, *37*(9–10), 653–668. https://doi.org/10.1108/F-01-2018-0006
Rahla, K. M., Mateus, R., & Bragança, L. (2021a). Implementing circular economy strategies in buildings—from theory to practice. *Applied System Innovation*, *4*(2), 1–14. https://doi.org/10.3390/asi4020026
Rahla, K. M., Mateus, R., & Bragança, L. (2021b). Selection Criteria for Building Materials and

Components in Line with the Circular Economy Principles in the Built Environment—A Review of Current Trends. *Infrastructures*, *6*(4). https://doi.org/10.3390/infrastructures6040049
Reeves, T., Olbina, S., & Issa, R. R. A. (2015). Guidelines for using building information modeling for energy analysis of buildings. *Buildings*, *5*(4), 1361–1388. https://doi.org/10.3390/buildings5041361
Remøy, H. (2010). *Out of Office: A Study on the Cause of Office Vacancy and Transformation as a Means to Cope and Prevent*.
Remøy, H. (2014). Chapter 5: Building Obsolescence and Reuse. In S. J. Wilkinson, H. Remøy, & C. Langston (Eds.), *Sustainable Building Adaptation: Innovations in Decision-Making* (pp. 95–118). Chichester, West Sussex, UK: John Wiley & Sons, Ltd Registered.
Remøy, H., & Van Der Voordt, T. J. m. (2007). A new life: conversion of vacant office buildings into housing. *Facilities*, *25*(3–4), 88–103.
Ross, B. E. (2017). The Learning Buildings Framework for Quantifying Building Adaptability. *AEI 2017: Resilience of the Integrated Building - Proceedings of the Architectural Engineering National Conference 2017*, 1067–1077. https://doi.org/10.1061/9780784480502.089
Ruuska, A., & Häkkinen, T. (2014). Material efficiency of building construction. *Buildings*, *4*(3), 266–294. https://doi.org/10.3390/buildings4030266
Sahai, A., & Casati, F. (2004). *Business Process Management*. https://doi.org/10.1201/9780203507223.ch32
Sanchez, B., & Haas, C. (2018). Capital project planning for a circular economy. *Construction Management and Economics*, *36*(6), 303–312. https://doi.org/10.1080/01446193.2018.1435895
Scolaro, A. M., & De Medici, S. (2021). Downcycling and upcycling in rehabilitation and adaptive reuse of pre-existing buildings: Re-designing technological performances in an environmental perspective. *Energies*, *14*(21). https://doi.org/10.3390/en14216863
Sedova, A. (2022). Impact analysis on adaptive reuse of obsolete ecclesiastical cultural heritage. *European Journal of Cultural Management and Policy*, *12*(December), 1–16. https://doi.org/10.3389/ejcmp.2022.11083
Shahi, S., Esnaashary Esfahani, M., Bachmann, C., & Haas, C. (2020). A definition framework for building adaptation projects. *Sustainable Cities and Society*, *63*(June), 102345. https://doi.org/10.1016/j.scs.2020.102345
Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information*, *22*(2), 63–75. https://doi.org/10.3233/EFI-2004-22201
Thomsen, A., & Van Der Flier, K. (2011). Understanding obsolescence: A conceptual model for buildings. *Building Research and Information*, *39*(4), 352–362.
van Stijn, A., & Gruis, V. (2020). Towards a circular built environment: An integral design tool for circular building components. *Smart and Sustainable Built Environment*, *9*(4), 635–653. https://doi.org/10.1108/SASBE-05-2019-0063
Ventresca, M. J., & Mohr, J. W. (2002). Chapter 35: Archival Research Methods. In *Baum* (The Blackw, pp. 805 – 828). Hoboken, New Jersey, USA: Wiley-Blackwell.
Webb, R. S., Kelly, J. R., & Thomson, D. S. (1997). Building services component reuse: An FM response to the need for adaptability. *Facilities*, *15*(12–13), 316–322. https://doi.org/10.1108/02632779710188306
Wilkinson, S. J., Remøy, H., & Langston, C. (2014). Sustainable Building Adaptation: Innovations in Decision-Making. In S. J. Wilkinson, H. Remøy, & C. Langston (Eds.), *Sustainable Building Adaptation*. Chichester, West Sussex, UK: John Wiley & Sons, Ltd Registered.
Xiao, Y., & Watson, M. (2019). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research*, *39*(1), 93–112. https://doi.org/10.1177/0739456X17723971
Xing, K., Kim, K. P., & Ness, D. (2020). Cloud-BIM enabled cyber-physical data and service platforms for building component reuse. *Sustainability (Switzerland)*, *12*(24), 1–22. https://doi.org/10.3390/su122410329

Yin, R. K. (2014). Case Study Research Design and Methods. *Canadian Journal of Program Evaluation*, *37*(1), 282. https://doi.org/10.3138/CJPE.BR-240

Appendix A: Interview Protocol

A.1 Introduction

Welcome to this interview on the topic of obsolescence and vacancy in the property market and the built environment. These issues have become increasingly prevalent in recent years, as buildings are left unused or underutilized due to changing societal needs and technological advancements. One potential solution to this problem is adaptive reuse and building adaptations, which repurpose existing structures for new uses rather than building from scratch. Adaptive reuse is also effective circular practice, as it facilitate the reuse of the materials and assets.

The aim of this research is to create practical guidelines for professionals on how to implement circularity and adaptability when repurposing vacant and obsolete real estate properties.

Before we begin, I would like to confirm that you are aware that this interview will be conducted and recorded for research purposes.

This interview will be conducted according to the polices of the Human Research Ethics Committee (HREC) at TU Delft. The privacy of your information is highly considered.

1. May I have your consent to conduct and record this interview?"

A.2 Opening Questions

1. To what extent do you believe that building vacancy or obsolescence is a problem in the Dutch real estate? Why?
2. How do you think circularity can contribute to this problem ? Why?
3. How do you see the importance of facilitating the adaptability in existing real estate? Why?

A.3 Key Questions

1. Why did you transform this project in an adaptable and circular way?
2. What are the key aspects that you did consider for adaptability and circularity?
3. What are the circular and adaptable things (solutions) did you do to make this transformation adaptable and circular ? Can you give me an example ?
4. What are the guidelines/sources did you follow ?
5. How did you use these guidelines ? (can you elaborate more with examples)
6. What are there any obstacles you face in these guidelines ?

A.4 Closing Questions

1. How do you see the future of considering circularity and adaptability in transforming vacant and obsolete buildings in the Netherlands?
2. Is there any information you would like to add or share?

Thank you