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Review

Adaptability of Buildings: A Critical Review on the Concept Evolution

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Abstract: Our ever-evolving built environment is continuously facing emerging needs for housing, work, health, and mobility, among others. Yet, buildings are usually designed and set up as finished permanent objects, reflecting the one constant scenario in mind of defined form, function, and performance. Since change is increasingly inevitable in our life, enlarging buildings' adaptive capacities in response to arising variables and changing conditions over their lifecycle becomes a necessity in seeking global sustainability demands. The concept of building adaptability has been a notable subject in this respect, increasingly stimulating and proposing regenerative alternatives to today's often obsolete buildings. This paper critically reviews the existing body of knowledge on the concept of adaptability in building research. The main focus is made on the evolution of the concept interpretations and related paradigms, and on the development of its applications and strategies in the light of promoting models and trends. Drawing on the literature as a source of evidence, the paper analyzes and classifies the content of existing studies published in scientific journals and gray literature, focusing on a timeframe from 2015 up-to-date. Moreover, the paper aims to build a constructive discussion to identify potential gaps between the actual state of the art and emerging needs, which should be addressed by further research.

Keywords: adaptability; adaptable building; building adaptation; flexibility; open building; shearing layers; building decomposition; circular economy; resilient building

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1. Introduction

Our built environment is constantly coping with challenges at multiple levels and in several areas [1]. Rapid urbanization, technological innovations, and climate change are among the challenges that our society is confronting in an accelerated and unprecedented way [2]. Buildings as a major component of the built environment are frequently prompted to change in response to these challenges. Nevertheless, they are usually designed and constructed as rigid, fixed, monofunctional structures, which disable any type of change. Moreover, multiple built environment problems are directly linked to the poor use of buildings, often associated with high flows of materials and energy [3]. These reasons explain why buildings recurrently end up as obsolete objects when users' preferences change and new society needs arise. As a result, these outdated structures bring on high building vacancy rates (building redundancy) leading to substantial refurbishment [1] or premature demolition that both imply high costs and create large amounts of waste, which is only partially reused or downcycled into lower quality products. Given all that, current building practices ineffectively consume substantial quantities of virgin resources and significantly contribute to environmental degradation and climate change.

Seeking global sustainability and technology demands requires a shift in our design culture of buildings towards embracing a new vision in which those are created to flexibly cope with the different variables over their life time. Currently, changes are inevitable—even sometimes on a daily basis—and the context of future buildings is surrounded by uncertainties (e.g., climate predictions, availability of fuel and building materials) [4]. These changes might occur over the lifecycle of a building often irregularly and without being contemplated earlier when the building was initially designed and constructed [5]. Yet, these issues often count on a building's capacity to adapt and keep functioning for a maximum useful lifespan. All bring up the fact that static permanent buildings are no longer an option in our modern life [6].

The concept of adaptable buildings has always been a notable subject in addressing issues of building obsolescence and redundancy. The term "adaptability" usually refers to the capacity of buildings to change in response to varying needs. However, the essential value of adaptability comes about—in large part—the impossibility to predict future changes [2]. These changes can be related to social and local factors (e.g., user's preferences, cultural demands, existing materials), environmental motives (e.g., natural hazards, climatic changes such as heat waves), technical requirements and functional performance (e.g., to embrace technological improvements) [7], economic factors, legislative issues (e.g., regulations and policies) [1], stakeholders interests [8], and others [1,4,9].

The theme of building adaptability remains a major interest for scholars and practitioners [10] across multiple disciplines, including architecture, engineering, planning, and management [5], where adaptable buildings are largely perceived as intrinsic to a sustainable built environment [11,12]. This is stemmed from their potential of avoiding premature demolition and preserving the value of materials and embodied energy, together with the costs associated with the production of new materials [2,13]. This also implies the extension of the building useful life since changes can happen while preserving a significant part of a building [4].

Resources scarcity and environmental degradation caused by building-related activities together with the huge investment in refurbishment projects in European countries further emphasize the importance of building adaptability, as it promises to extend the economic viability of buildings and minimizing maintenance costs [4,7].

Furthermore, the adaptive reuse of buildings plays a decisive role in emissions reduction and supports global climate protection [14]. A direct relationship can also be found between buildings' adaptability and climate change main research directions in the built environment: adaptation and mitigation [9]. While mitigation strategies deal with the causes of climate change, adaptation strategies target the consequences and outcomes resulting from climatic changes.

Given all of the above, designing future buildings for adaptive capacities is a crucial condition for sustainability, and therefore, the purpose of this paper is to identify potential research directions by reflecting on the evolution of current trends and strategies that promote the concept. The discussion also highlights the contribution of adaptability to both mitigation and adaptation studies of climate change, particularly in investigating relationships with circularity of buildings and resilient design. The scope of the paper covers key adaptability research themes, including definition and various interpretations, associated concepts, features and dimensions, underlying theories and models, together with application strategies. Furthermore, potential gaps are also identified, providing insights for future research.

The paper is organized as follows: Section 2 describes the research methods adopted to meet the objectives of this study and the research design pursued to discuss the findings of the review. The findings are presented and discussed in Section 3 under three main themes. A concluding discussion and open research questions are presented in Section 4. Finally, Section 5 wraps up and summarizes the overall findings.

2. Materials and Methods

2.1. Literature Review Approach

As referred above, the main purpose of this paper is to critically reflect on the existing body of knowledge in the field of adaptability of buildings. To this end, an exploratory, interpretivist approach is used to discuss the current state of the art, in order to identify knowledge gaps and catalyze potential research opportunities for future agendas. By means of a systematic literature review, a descriptive and exploratory analysis of literature data is conducted to examine how the concept of adaptability in buildings has been interpreted and implemented by scholars and practitioners within the scope of the built environment. The method chosen is adequate for mapping, assessing, and synthesizing literature studies to feed the knowledge of the field concerned with the study [15].

In order to carry out a review that is systematic, transparent, unbiased, and replicable, a protocol based on the research objectives should be developed [16,17]. This protocol allows the review methods to be criticized and improved. The protocol should include a description and rationale for the review objectives, intended research methods, criteria for the inclusion of studies, and methodology for data extraction, processing, and synthesizing [18]. Moreover, adopting a specific SLR (Systematic Literature Review) methodology enriches the evidence legitimacy and results authority. A research protocol was therefore formulated perusing systematic and methodological rigor. The review protocol is based on Tranfield et al.'s [15] categorization of review stages, and Briner and Denyer's [17] protocol template, adapting from Cochrane Institute's handbook for systematic reviews [19]. Table 1 presents the SLR protocol developed for this study.

The different stages of the adopted procedure are further detailed in the next subsection.

2.2. Stages of Systematic Review Protocol

2.2.1. Planning

According to the protocol decided upon for this study, the first step to conduct the intended review was to lay a background for the problem to be examined and develop a rationale behind the theme selected to address this problem from the authors' point of view. However, the problem of building obsolescence due to changes of multiple natures was stated in the introductory section where the importance of buildings' adaptability and its relevance to address change were made clear. Subsequently, the initial research question was formulated: "What makes adaptability of buildings essential in addressing change?" The formulation of initial research question is important as it guides the review by informing about the studies to be included and the strategy to be followed in identifying those studies and later the data to be extracted from each study [17]. Yet, to be more specific, the focus of this review was oriented towards the following objectives:

1. Exploring the evolution of the concept and its underpinning theories and interpretations.
2. Identifying design enablers for adaptable buildings.
3. Identifying recent development of building adaptability and investigating strategies for implementation in light of current trends and technologies.
4. Identifying gaps and potential opportunities for future consideration.

Table 1. Systematic literature review protocol for this study.

Protocol Stages	Protocol Steps	Research Aspects
1. Planning	Background to review	Problem: building obsolescence due to emerging needs and contextual changes. Rationale: building adaptability has provided multiple strategies to address multiple challenges related to changes of contextual conditions. Initial RQ: what makes adaptability of buildings essential in addressing change?
	Objectives statement	Primary objective: 1—Exploring the evolution of the concept and its underpinning theories and interpretations. 2—Identifying design enablers for adaptable buildings. 3—Identifying recent development of building adaptability and investigating strategies for implementation in the lights of current trends and technologies. 4—Identifying gaps and potential opportunities for future consideration. Subquestions: • What is meant by adaptability? • What are the various interpretations of the concept within the scope of built environment? • Adaptable to what (change factors)? • What are the types/dimensions of adaptability in buildings? • What is the difference between adaptability and flexibility? • How did the concept emerge in the built environment? • What are the system specifications that make a building adaptable? • What facilitate a building's adaptability in terms of design? • What are the current trends and strategies that promote the implementation of the concept? • What are the opportunities to improve the adaptability of buildings?
2. Processing	Criteria for selecting studies	Context: built environment, particularly individual buildings and buildings' components Interventions, mechanisms, and outcomes: strategies, theories, practical examples, concepts, principles, guidelines, recommendations Types of studies: both qualitative and quantitative
	Search strategy for identification of studies	Databases: ISI Web of Science, Scopus, and Science Direct (Table 2) Timeframe: 2015 to present time of the study Keywords: adaptable building, adaptive building, adaptability of buildings, building adaptability, building adaptation, adaptive reuse, design for adaptability Language: English only Article type: indexed journal papers, conference proceedings, books, book chapters. Gray literature: included

Table 1. *Cont.*

Protocol Stages	Protocol Steps	Research Aspects
3. Analysis	Eligibility	Inclusion/exclusion criteria: (Table 3) Number of reviewers screening the articles: 3
	Quality appraisal	The quality of papers is assessed by the three reviewers and the paper is included when approved by at least two of them
4. Extraction and Reporting	Data collection	Full text of eligible articles is screened and analyzed; meanwhile, more sources and studies are added at this stage. The data extraction corresponds to three themes: 1. concept interpretation, 2. dimensions and overlapping concepts, 3. promoting models and design enablers
	Results synthesis	Type of synthesis: interpretation of results under descriptive and exploratory analysis of the bibliographical research content

Table 2. Filters applied to database search.

Filters	Databases		
	Web of Science	Scopus	Science Direct
Search in	Topic field that includes Keywords, Abstract, Title And Topic	Article Title, Abstract, Keywords	Title, Abstract or Author-Specified Keywords
Categories	• Construction building technology • Engineering civil • Architecture • Environmental sciences	• Environmental science • Engineering	• Environmental science • Engineering
Article type	• Article • Proceeding paper • Review • Editorial material • Early access	• Article • Conference paper • Book Chapter • Review • Conference Review • Editorial	• Research articles • Review articles • Book chapters • Conference abstracts
Language	English	English	English
Timeframe	2015 to time of study	2015 to time of study	2015 to time of study

Table 3. Inclusion and exclusion criteria for obtained studies.

Criteria	Inclusion	Exclusion
Article type	Primary and secondary literature resources including journal papers, conference proceedings, book chapters, editorials, abstracts	-
Accessibility	Online availability of full text, or obtained by requesting full texts from authors	Inaccessibility to full text
Research scope	Built environment, particularly buildings and buildings components	Any other field
Language	English	Any other language
Timeframe	2015 to time of study	2015 to time of study

Since the literature on adaptability of buildings is significantly broad and diverse, the initial research question was broken down into subquestions to establish a focus that is specific enough to be addressed in a systematic review. The following subquestions were formulated to facilitate the development of the review methods:

- What is meant by adaptability?
- What are the various interpretations of the concept within the scope of built environment?
- Adaptable to what (change factors)?
- What are the types/dimensions of adaptability in buildings?
- What is the difference between adaptability and flexibility?
- How did the concept emerge in the built environment?
- What are the system specifications that make a building adaptable?
- What facilitate a building's adaptability in terms of design?
- What are the current trends and strategies that promote the implementation of the concept?
- What are the opportunities to improve the adaptability of buildings?

2.2.2. Processing

The initial search process made use of three scientific search engines and academic databases: ISI Web of Science, Scopus and Science Direct. The consideration of multiple databases ensures a comprehensive coverage of studies; Web of Science allows for reaching all indexed journals with measured impact factor in the citation report of the journal [20]; Scopus provides access to the largest database of reviewed articles [21]; Science Direct provides access to international multidisciplinary studies. The time period for the search was set from 2015 to the actual time of this study. Only articles written in English were considered for this review. Studies of qualitative and quantitative natures developed within the scope of built environment, particularly examining buildings and building components, were considered for this review. Relevant keywords such as adaptable building, adaptive building, adaptability of buildings, building adaptability, building adaptation, adaptive reuse, and design for adaptability were employed in this first level of the search. Table 2 presents the filters applied for each database search.

2.2.3. Analysis

The analysis of studies obtained from the database search was performed according to the inclusion and exclusion criteria set by the authors (presented in Table 3). Primary and secondary resources with focus on buildings and built environment were considered including indexed journal papers, conference articles, book chapters, editorial materials, dictionary entries, and others. The inclusion of gray literature was found important to produce a comprehensive and transparent study. Briner and Denyer state: "As systematic reviews should ideally include all studies and data relevant to the review question that meets the inclusion criteria, they should, therefore, ideally seek out as much unpublished data and gray literature as possible" [17] (p. 120). Articles were screened for inclusion or exclusion by all three authors who also assessed their quality. Articles were considered for review when at least two out of the three authors approved they met the criteria of inclusion and quality and relevance appropriate for the SLR scope. Results of database searching and articles screening are presented in Figure 1.

The full texts of eligible articles were screened and analyzed at this stage. However, since searching electronic databases is unlikely on its own to be sufficient [17], a second level of search was employed using other techniques, including running through the bibliography of published review and searching studies cited by scholars. The studies considered at this level of research are not restricted to the initial timeframe. The second level search resulted in adding more 60 articles to the review (Figure 1). The inclusion of those additional articles was found important to reflect on the evolution of the concept utilization.

2.2.4. Extraction and Reporting

The extraction of data was based on three main themes deemed adequate to meet the objectives and address the research questions intended for this review. Figure 2 presents the themes and subthemes addressed by this review.

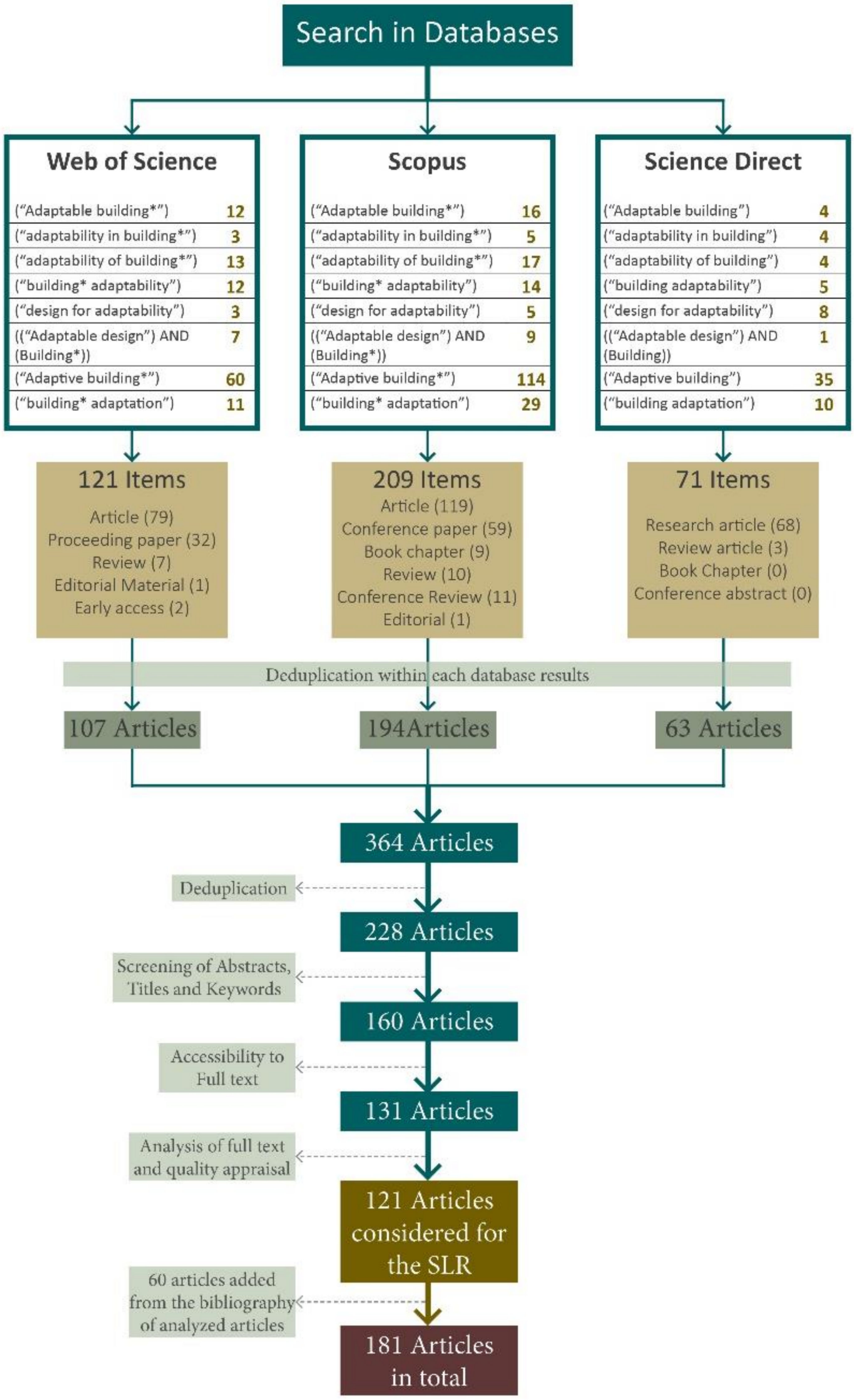

Figure 1. Results of database search.

The strategy followed in this paper is to first consult the various definitions, interpretations, perceptions, and utilizations of the concept of adaptability in the scope of the built environment to conclude key characteristics that identify adaptable buildings and deliver an operational definition that comprehensively embraces adaptability features (theme 1). As the concept found to have a versatile use, the various dimensions, types, and related/complementary notions are investigated to identify the various contexts and conceptual possibilities of application that correspond to the types of change (theme 2). Four main models are recognized as underpinning design enablers for the development and promotion of adaptability application: the open building, shearing layers and decomposition methods, the circular economy in the built environment, and the resilience theory. These models contributed to shape evolution of the concept of adaptability; therefore, their proposed strategies are further discussed in terms of relevance and furtherance of adaptability facets (theme 3).

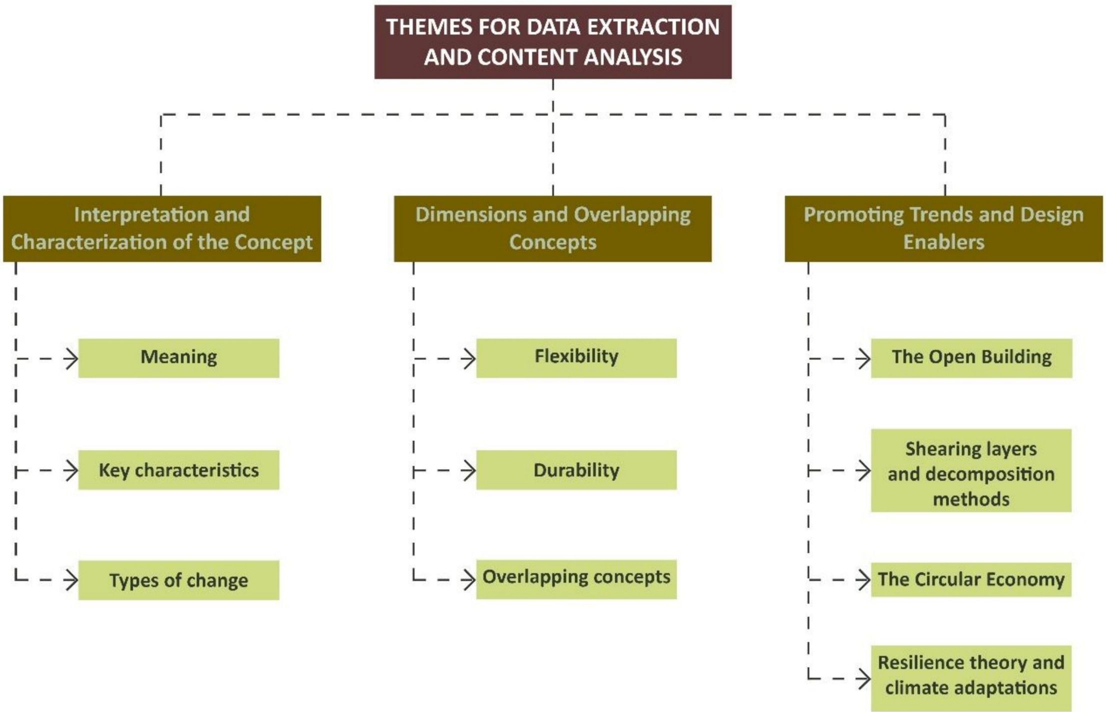

Figure 2. Themes for data extraction and content analysis.

Following the extraction of data, a content analysis of each theme is performed. The analysis is presented in the following section.

3. Content Analysis

3.1. Interpreting the Concept of "Adaptability"

Being adaptable is defined in the dictionary as "capable of adapting or of being adapted" and to adapt is "to make suitable to or fit for a specific use or situation" [22]. Adaptability can similarly be defined as "the ability to change (or be changed) to fit changed circumstances" [22]. In systems engineering, adaptability can be defined as "the ability of a system to change internally and autonomously to follow changes in its environment" [23] (p. 2). In product design, adaptable design is a new design paradigm that aims at creating designs and products that can be easily adapted for different requirements [24] (p. 1367).

In the scope of the built environment, there is a lack of consensus on the exact meaning of the term "adaptability" as it has been used differently according to a particular context [25] where a certain level of adaptation applies [12]. Habraken [26] confirms this idea in the architectural discourse, he affirms "Words like 'adaptability', 'flexibility', and 'polyvalence' have multiple and often overlapping meanings that make it virtually impossible to come up with a vocabulary acceptable to everybody" [26] (p. 290). The concept of adaptability has been also approached by defining the so-called "maladaptive" building as the "one that cannot match the new demands placed upon it, due to being technically nonviable or cost inefficient" [1] (p. 144). Table 4 summarizes the multiple definitions by various scholars who used the term with reference to different building typologies, types of change, and motives.

Table 4. Adaptability definitions.

Building Typology	Definition	Type of Change	Motives	Sources
Housing	Adaptable housing is the one that can adapt to users' changing physical needs, in particular as they get older or lose their mobility	Accessibility, furniture (spatial)	Users' physical restrictions	[27]
Office building	Adaptability is a mean of increasing usability and extending buildings functional lifespan	Change of use	Long-term vacant office buildings	[28]
Office building	Adaptability describes a building of 1. multifunctional use (generality); 2. built-in possibilities to rearrange, take away, or add elements (flexibility); 3. possibility of division into different functional units or extendibility (elasticity)	Change of use or function, spatial arrangements, change of size	Rapid change in private and public organizations, building redundancy	[8]
General	Adaptability features a system's ability to adapt itself towards changing environments	Interior changes	Varying operating conditions	[29]
General	Adaptable architecture is "an architecture from which specific components can be changed in response to external stimuli, for example the users or environment"	Spatial flexibility and constructional openness	Changes both in the social, economic, and physical surroundings, and in the needs and expectations of occupants	[12] (p. 167)
General	"The capacity of a building to accommodate effectively the evolving demands of its context, thus maximizing value through life"	Spatial, structural, and service strategies	Changing operational parameters over time	[30]
General	"A building that has been designed with thought of how it might be easily altered to prolong its life"	-	Building obsolescence	[31] (p. 8)
General	Building adaptation as the ability of a building to fit within new conditions or needs by means of reuse or upgrading	Change in performance for existing buildings	-	[32]
General	Structural adaptability is "The capacity of the building structure to be able to undergo changes to the structure itself, with or without only small consequences for the remaining building storeys"	Structural	Structural obsolescence and inflexibility leading to economic unviability	[33] (p. 2)
General	"The ease with which buildings can be physically modified, deconstructed, refurbished, reconfigured, repurposed, and/or expanded"	Changes in space, size, layout, components, use, and function	Building obsolescence leading to premature demolition	[2]
General	Ability to be changed or modified to make suitable for a particular purpose"	-	Building obsolescence leading to premature demolition	[34]
General	The adaptive capacity of a building includes all characteristics that enable the building to keep its functionality through changing requirements and circumstances, during its entire technical lifecycle and in a sustainable and economically profitable way		Obsolescence and economic unviability	[35] (p. 569)

Most studies recognize issues of building obsolescence and inadequacy resulting from changing operational conditions, emerging needs of users, and varying environmental and external factors as the lead motive for designing adaptable buildings. Literature definitions of adaptability reflect on the capacity to accommodate change as an overall feature of adaptable buildings [4]. Yet, the essence of change builds upon the particular motives and corresponds to the varying needs. Scholars discussed multiple types of change such as change of use or function (to the same or to another use type), changeable parts or components, space plan, layout, size or volume, and performance changes. However, change of buildings' use is the dominant type in the literature [1,3]. This is probably because users frequently tend to adapt the usability of their spaces to match their needs by their own, through conducting simple modifications (e.g., changes in furniture). In this respect, several studies perceive adaptability as a person-centric action triggered by user attitude to accommodate change, for example, by changing the use of one space [25,36]. Still, other changes in uses or functions may call for professional intervention in order to perform larger or more complex alterations, particularly when changing to another function (e.g., from office building to housing). Understanding these change factors is key to the development of buildings that are adaptable over their lifecycle [37]. The ideology of change in its various types is coherently associated with the concept of adaptability in literature dialogues, making it an umbrella concept to strategies and concepts linked to one or more of change scenarios such as extendibility or scalability, flexibility, recyclability, reusability, transformability, upgradability, convertibility, and durability, among others.

Operational conditions may change at any point over the lifecycle of a building just as different needs of users may arise. The static nature of conventional buildings ignores the provisional nature of architectural objects manipulated by the previous variables within a certain context. Incorporating adaptability thinking therefore calls for shifting the direct focus on form and function defined by actual needs towards contemplating long-term changes against a time perspective. Beisi [38] affirms that implementing adaptability does not imply a one-time solution but should allow for various possibilities overtime. Similarly, Schmidt et al. [30] consider that adaptability seeks a reconceptualization of time through switching attitudes and rethinking values. The time factor is hence considered a key enabler for change, allowing buildings to be perceived as dynamic systems that react in response to emerging needs [39] with long term consideration of the sustainability of the built environment. Adding a time factor to the design process stems from creating a certain context where a building is prone to the temporal reality of architecture in the face of change [30]. Adaptability thus involves additional knowledge of context conditions, purpose, and application, which may not be as clear at first glance [40]. Decisions about design and construction process of a building are usually derived from immediate needs and conditions, thereby shaping a certain context. Incorporating a time-based approach assumes that contextual conditions are not of a stable nature. Leaman et al. [40] confirm that successful adaptability strategies anticipate how contextual factors change over time. The contemplation of context enhances the capacity to be modified to fit new conditions, which is another quality of adaptable buildings discussed by several authors such as Douglas [32]. The fit in a traditional building is restricted to the limits of function and form defined by immediate considerations, while for an adaptable building, the fit is context-oriented and time-based [30], providing fit scenarios to both actual and future considerations.

A key objective of adaptability is the ability to prolong the useful life time of a building [31]. Most buildings become obsolete before their technical life comes to an end, thus being abandoned. This happens due to the discrepancy between the conditions of supply of space and the demands varying overtime [40]. A mere long-life building does not matter without a utility provided to its users. In all perspectives, people are always part of the equation, as buildings change to accommodate their changing needs, provide better service, and ensure their comfort and protection.

Synthesizing this discussion of adaptable buildings leads to a comprehensive definition of the concept of adaptability in buildings that is *"the capacity of a building to accommodate* *change in response to the emerging needs or varying contextual conditions, therefore prolonging its useful life while preserving the value for its users over time"*.

3.2. Dimensions and Overlapping Concepts

This definition of adaptability sounds simple and explicit enough to be understood. Nevertheless, literature on adaptability within the built environment context contains diverse interpretations, and that it reflects a high level of relevance with other concepts and terminologies [30,41] often utilized to contribute to the physical capacity of a building to adapt, such as Flexibility, Durability, Transformability, Upgradability, Convertibility, Accessibility (making spaces accessible for all life stages), Open Plan, and Performance-based building (which describes the performance dimensions of a building concerning functionality and preserving fit purpose over time) [42]. These strategies are manifestations of adaptability as far as they imply change, e.g., change in configuration, change in space dimensions, change of use or function, change of size, change of a building performance, and changeable building components. However, the permutations among these strategies make it rather difficult to categorize them into defined dimensions or types of adaptability.

Nevertheless, some studies made distinctions between adaptability types as in Schmidt et al. [30] that is considered by some scholars as the most comprehensive [25]. Schmidt et al. [30] articulate the physical capacity of adaptable buildings in six types: availability, extendibility, flexibility, refitability, movability, and recyclability. Table 5 summarizes the various terminologies and notions together with their relation to the different types of adaptability by considering the type of change they imply.

Table 5. Adaptability dimensions and overlapping concepts.

Terminologies	Description	Linkage to Adaptability	Type of Adaptability	Context	Sources
Open Plan	Free of structural, mechanical and other obstructions. Components in the space plan layer can be more easily reconfigured to suit changing functional requirements	Open plan layouts grant facilitated adaptation of interior spaces with minimized impact on the existing structure and systems	Space plan adaptability to fit changing functional needs	More common in commercial buildings and warehouses	[2,43]
Transformability	The ability of a part of a complex adaptive system to assume a new function	Adaptability manifests in short-term behavior while transformation into a new state refers to a longer period as it results from multiple adaptations	Functional adaptability	Resilient building systems	[44,45]
Changeability	Changeability has four aspects: adaptability, flexibility, robustness, and agility	Allows products changeability across products platforms	Adaptability as a subset of products changeability implies internal changes to systems	Companies' product families or platforms	[29]
Generality	The ability of a building to meet changing functional purposes without changing its core properties (passive support for change)	A concept/dimension of adaptability	Multifunctional use	Office buildings	[8,43,46]
Flexibility	"The ability of a building to meet changing functional user or owner needs by changing its properties easily" [8] (p. 121)	A concept/dimension of adaptability	Rearrangement of elements and systems	Office buildings	[8,30,47]
Elasticity	The ability of a building to be extended, shrunk, or partitioned as required	A concept/dimension of adaptability	Dividing space into different functional units, changing the size of a building	Office buildings	[8,43]
Simplicity	Designing simple structural systems, (e.g., repeating layouts and grids, larger but fewer components). The absence of complex systems vital for the continued operation of the building	Creates easily understood load paths, reducing therefore the uncertainty for designer working on adaptable solutions	Physical modification, deconstruction, refurbishment, reconfiguration, repurpose, and/or expansion	General	[2,3]
Commonality	Using the same component sizes and construction details throughout a building; commonality reduces uncertainty	Repetition of the same components and details facilitates replacement, adaptation, and systematic reuse	Physical modification, deconstruction, refurbishment, reconfiguration, repurpose, and/or expansion	General	[2]
Modularity/Standardization	The standardization of components sizes and interfaces	Facilitates reconfiguration of spaces, reuse and replacement of components	Changeable components; spatial configurability	Common in office cubicles, production of modular rooms	[2]
Convertibility	Determines the ability of buildings to shift between different uses/functions	Adaptable use of space	Change of use/purpose/function	General	[1,3,30,36,48]
Versatility	Represents the physical change of space (i.e., spatial layout)	Versatility is a branch of flexibility that is a strategy of adaptability	Change of space and layout	General	[30,36]

Table 5. *Cont.*

Terminologies	Description	Linkage to Adaptability	Type of Adaptability	Context	Sources
Scalability	Increasing/decreasing the building size	A dimension of adaptability	Change of size	General	[30,36,48]
Movability	Changing configurations/locations	A dimension of adaptability	Change of location	General	[30,36,48]
Reusability	Used again in its original form	A dimension of adaptability	Changeable components	General	[30]
Availability	Accessing a ready set of components	Access to adequate components facilitate adaptability	Changeable components	General	[30,47]
Refitability	Exchanging, replacing, or renovating components	The ability to replace components increases adaptability options	Changeable components; change in performance	General	[30,36,47]
Expandability/Extendibility	Facilitating additions to the quantity of space in a building	Accommodate much higher densities in the same building with the same footprint and infrastructures	Increasing the size of a building	General	[3]
Upgradability	Choosing systems and components that anticipate and can accommodate potential increased performance requirements	Upgradable components allow performance adaptability	Changeable components; performance adaptability	General	[3]
Adaptive reuse	Defined as the process of extending the useful life of historic, old, obsolete, and derelict buildings	Reuse of existing structures	Performance	Existing buildings/historic buildings	[41]

Still, a distinct relationship that is always present in mechanisms and models of application of adaptability can be spotted with the concepts of Flexibility and Durability.

Flexibility: The term "flexibility" is the one most confused with adaptability in the literature by far, as both frequently appear together [25,40,48]. However, there are multiple inconsistencies in scholars' distinction and identification of each of the concepts. For example, Gu et al. [24] refer that adaptations are carried out by an outsider (e.g., the user or the designer), while flexibility implies internal changes to fit external ones. Conversely, other scholars such as Fricke and Schluz [29] think that adaptability copes with changing environments without external changes, while flexibility implies changes from external. For Blakstad [42], adaptability is a response to both internal and external changes, while flexibility is a solution-oriented strategy that makes it limited to certain alternatives [42]. From another perspective, multiple studies consider that both concepts carry similar meanings as in Manewa et al. [1], others even use both terms interchangeably, particularly when it comes to practice. Pinder et al. [25] confirm that construction practitioners and professionals tend to use the two concepts as synonyms. Studies might also show a conflict in relevance to the speed of change, frequency, and magnitude between the two concepts. Leaman et al. [40] refer to flexibility changes as short-term, quicker, and of a relatively lower magnitude while they see that adaptability implies larger-scale changes of major magnitude over long-term periods. By this meaning, a building can be adaptable without being flexible and vice versa. As for Till and Schnieder [27], adaptability is limited to users' changing physical needs as when they become older or lose mobility. The authors consider that the term flexibility refers to a wider range of interventions than those offered by adaptability. Still, the general perception of flexibility in the literature is a mean to achieve a certain level of adaptation.

Durability: In most studies, the concept of durability is often associated with the concept of adaptability [2–4,25,49,50] since in order to design structures that support multiple uses and loading scenarios, they should be sufficiently strong [49]. Changes in functions of a building often entail changes to the required design loads [2]. Therefore, structures should be designed to sustain the worst case scenario [4]. Many practitioners consider durability a key facet of adaptability since a combination of durable structures (long-life) with loose-fit space is a main way to achieve adaptability [25]. Similarly, other studies reflect on the concept of durability that aims at extending the useful lifetime of materials and technology in buildings as complimentary to adaptability [3] since it significantly influences the level of change by allowing a certain level of flexibility in the way spaces are used.

3.3. Enablers and Promoting Models

The general understanding of adaptability stems from shifting the conventional perception of a building as a finished, static object towards contemplating it as a dynamic system that consists of the object and the process of construction, change, deconstruction, and reconstruction. Design for adaptability comes about the issue of building obsolescence that is evidently associated with environmental and economic impacts resulting from resource consumption and material loss [49]. The ideology of adaptability of buildings provides a multifaceted theory and set of principles for sustainable and resilient built environment where adaptability can refer to function, structure, space, components, systems, services, and size, manifesting in active and passive patterns of response [25]. This is revealed by literature studies where adaptability is discussed with links to "Open Building" [51], flexibility [25,40,48], resilience (as a key theme in the Sustainable Development Goals (SDGs) [52]), "Circular Economy" principles [53], and design for change [37]. These ground concepts and their basic principles gradually shaped the evolution course of the concept of "adaptability" and enabled the development of its strategies. Some of these enablers are highlighted in the following paragraphs.

3.3.1. The Open Building

The "Open Building" approach is often assumed to be the underpinning foundation of the concept of Design for Adaptability (DfA) that holds a fundamental sense of flexibility [54]. The "Open Building" concept roots back to the 1960s when the post-WWII housing crisis was confronted with a movement to empower users. The escalating land values and scarcity of land in cities led to consideration of smaller and more efficient housing units inserted into multifamily residential buildings [55]. The idea behind the open building approach was first introduced by the Stichting Architecten Research (SAR) and through prominent architects like N. J. Habraken in the 1960s. Habraken criticized in his book *Supports: An alternative to mass housing* [56] the state of uniformity that many of housing estates suffer from, pointing out the failure of architecture to meet the diversity of society, by imposing design decisions that occupants should have made themselves according to the timeline they define. The "Open Building" term implies a notion of simple structures that easily succumb to flexibility and change overtime [3]. Given that, Habraken suggested a separation between two building elements: the structural support "Base building" subjected to the investor decision, and the flexible infill "fit-out" that follows inhabitant's decision [57]. The "Base building" consisting of the fixed structure (e.g., structural pillars, beams, slabs) is usually considered the durable rigid part while the infill or "fit-out" (e.g., windows and doors, interior walls, furniture) is formed by the flexible parts that are exposed to recurrent changes [33,58,59]. Both durable and flexible systems are integrated with minimal interface problems, thus facilitating a building's adaptability to users' needs changing overtime [4,59], for example, separating the envelope system from the structure by designing a specific interface allowing functional separation between those systems [3].

Spatial flexibility was among the primer drivers of the open building concept [55]. A prominent example in this regard is the Japanese traditional single family house that approached spatial flexibility by adopting rectangular plans for easy subdivision with moveable partitioning system of sliding interior panels and foldable partitions [55]. The interior spaces were divided to allow for a certain arrangement of "tatami" mats (floor coverings of standardized sizes) (Figure 3). At a later stage, the Japanese further contributed to the concept by creating distinct ownership patterns for each of the infill and support. The Japanese example is of a particular importance for showing the technical feasibility of the concept where huge efforts were implied, although met with modest success [26,30]. However, the Japanese government released multiple regulations to promote the so-called skeleton-infill (SI) construction systems, perceiving their potential in prolonging the lifecycle of building and reducing waste generation [59].

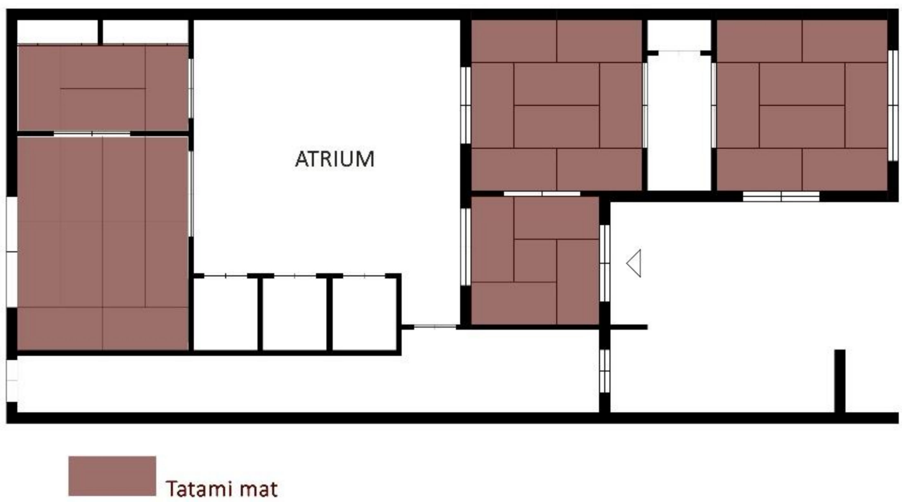

Figure 3. An example of a Japanese traditional house.

The Dutch experience is another example worth mentioning. Dutch architects were focused on social housing in the mid-20th century as they divided plans into large multi-functional spaces of identical sizes. The spaces served as bedrooms at night, study spaces during the day for younger members of the family, and living areas in the evening [55].

The influence of social housing on the development of thoughts and strategies related to Open Building was a great deal as this strategy was used in the organization of informal settlements [60], providing affordable yet quality dwellings and controlling future expansions by residents. In the same context, another approach was also introduced by the incremental housing methodology, which is a flexible approach largely adopted in housing crisis and emergency architecture situations to ensure accessible and affordable solutions that at the same time guarantee users' satisfaction [61]. Architect Alejandro Aravena implemented the incremental approach in his project in "Quinta Monroy" in Chile (Figure 4).

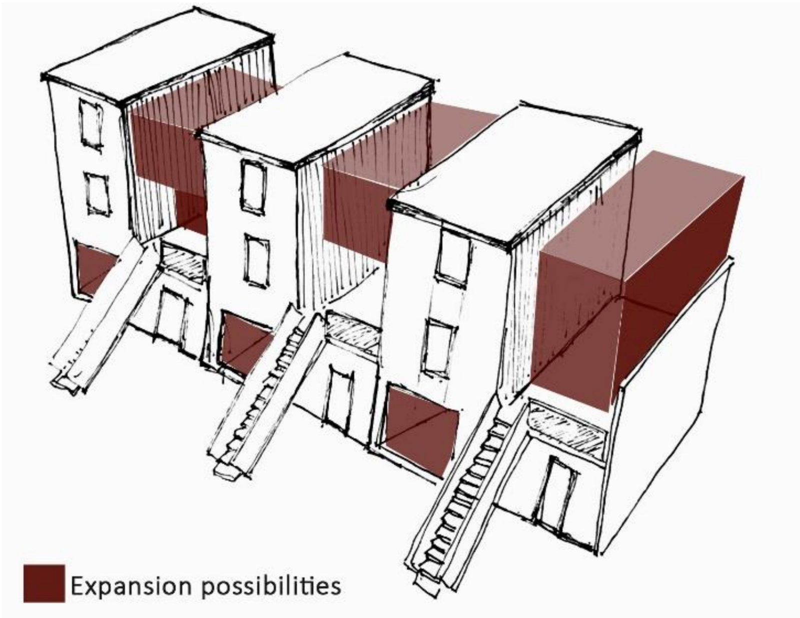

Figure 4. The incremental housing methodology in the Quinta Monroy project by architect Alejandro Aravena.

He referred to the process he used as "infrastructure as housing" as he developed two-story half houses with free spaces left between them, allowing for future expansions to be performed by the residents according to specific guidelines [61]. Each half house formed a core of a home and contained all the basic and essential element and utilities that require professional involvement, such as supporting structure, stairs, bathroom, and kitchen installations. The remaining elements—partitions, interior finishes, and the remaining enclosure—were left for the families to add according to their means and needs. The idea of incomplete housing was advocated by several authors such as Gosling et al. [4], who encouraged the concept of a structural frame with free space to be customized by the user.

Multiple studies built upon the open building concept to deliver strategies that facilitate adaptability of buildings, as it has been considered as the basis of adaptive design reuse strategies [58]. For example, a study conducted by Gijsbers [33] discusses that adaptability should be on both levels: infill and support. The author took the concept to a further level by allowing a flexible use of structural elements that contributes to extending the technical lifespan of a building. Gijsbers considers that a building structure should not disturb or limit infill change but rather facilitate it. He gives an example of movable columns on a certain grid, which would deliver a wider range of space layouts. Another solution addressing structural adaptability being a challenge against a building adaptations was introduced by Kokas et al. [62], who suggest a prefabricated modular system for apartment buildings.

Still and all, the real-life application of open building has been limited to standalone housing projects, geographically based in Japan and the Netherlands [63]. The practical examples failed to incorporate an inherent flexibility as proposed by the approach [64]. This is probably because the approach's main focus was on the separation between long-life and short-life elements without paying a proper attention on the classification of element durability. Geldermans et al. [57] justified this failure by arguing that the open building primarily focused on distinguishing decision power between each infill and support regardless the quality of materials and components. However, further regulations that promote the implementation of the concept were examined in Asia, including safety and durability enhancement of structures and provision of clear interior heights, which allow an increased flexibility for the infill system [59].

The open building approach remained as a philosophy as it fell short in delivering practical guidelines for designers to achieve an inherent adaptability. This is the reason why it remained inert for a while before rebounding later in the light of practical strategies that built upon its philosophy and complemented its insights with technical feasibility such as the Circular Economy in buildings.

3.3.2. Shearing Layers and Building Decomposition

A building system consists of a variety of functions and materials, all integrated in one closed entity of permanent status [65]. The rigid integration of these elements into structural systems to perform functions in particular space and time [66] ignores the level of durability pertaining to each component or building system [65], which often has a shorter lifecycle than the building itself [67]. The complexity of building systems resulting from the dynamic interactions and common dependencies between materials and components of different lifecycles makes it rather difficult for a building to change, meaning that any type of adaptation or alteration would be disabled as it entails ramifications on the overall performance of building structure [6]. Nevertheless, buildings are expected to last long despite all the changes that might occur during their service life, influencing their quality of response to emergent needs of users and other contextual factors.

The dynamic interactions and functional dependencies among building systems and components have been widely discussed in the literature of adaptability [4,49,54,68,69] as they largely influence its feasibility and interrupt its mechanisms. Multiple methods have been introduced by scholars to analyze a building composition and explore the interrelationships and interdependencies among its components, systems, and layers. Analyzing the complexity of systems considering the distinct lifespan of their components gives insights to investigating mechanism for change by identifying what elements should change and what types of dependencies would enable or interrupt this change.

The model of building layers is probably the most common approach in the literature, being an important design enabler of adaptability [39,49,68,69]. It assumes that a building system is made up of several layers, each defined by elements and functions of similar lifetime. Duffy [68] was the first to discuss the model of building layers as he considered the general perception of a building as rigid constant object to be invalid. Duffy identifies four layers of longevity of building components: shell (structure, 50 years), services (e.g., heating, plumbing, 15 years), scenery (fittings, decorations, 5–7 years), and set (e.g., furniture, daily). Duffy's early categorization of layers was later extended to six by Brand's approach of "Shearing Layers" (site, structure, skin, services, space plan, and stuff). Brand [69] introduced in his book, *How Buildings Learn*, a building composition of different hierarchal layers with different timescales that make it a dynamic system that transforms itself overtime. For instance, Brand's model suggests that components of a particular lifespan should have no direct interaction with longer life elements neither with shorter life ones. This separation guarantees facilitated and frequent changes and replacement of some elements without interrupting the general performance of the building. Further layers of different lifespans were later added by other studies using the same principle. The most recent identification of layers was done by Schmidt and Austin [70] who extended the model to nine layers: surroundings, site, structure, skin, services, space plan, stuff, space, and social.

Multiple scholars have built on the model of layers, proposing other methods of system's decomposition and categorization of elements. Durmisevic and Brouwer [6] argued that establishing specific decomposition characteristics of buildings defines the potential reuse of components and materials. Buildings therefore should be designed for a configuration that defines the relationships and levels of interdependencies and exchangeability among components allowing three-dimensional transformation: structural, spatial, and material. The transformation capacity of a building can be measured using performance indicators that correspond to the three dimensions. They proposed a hierarchy of four functional levels of building composition on material level (Building, System, Component, and Element) among which flexible connections should exist to facilitate change. Disassembles happen on building level to separate systems, then on system level to separate components, and finally on component level to separate elements and materials.

Another decomposition method was introduced by Hofer and Halman [71] who proposed categorizing products into platform-based families in order to standardize the arrangement of subsystems within a system layout. By doing so, they suggest dealing with classification of system and subsystem characteristics rather a component-level categorization. The approach supports an efficient and flexible positioning of products in companies, meanwhile it substantially decreases a system's complexity and improves its configurability. This happens by defining multiple hierarchical layers of product architecture. The layers are then to be used for identification of differentiation needs and commonality potential within each product family, taking into account market data and design dependencies. A similar approach was introduced by Levandowski et al. [72].

Again, Koh et al. [73] proposed two components classification schemes for identification of components for designing product variants and freeze planning. The suggested schemes rely on components connectivity and change risk evaluation to calculate a product likelihood of change and the impact resulting from that change in terms of the feasibility of reproducing the component to be changed. The resulting values are used to compute the common risks between components by considering indirect change propagation.

Schmidt et al. [30,39,54] focused on addressing the effects of particular components and subsystems on the capacity of transformation and reconfiguration of a building during its lifespan. The authors investigated the way components are clustered and the level of dependency between components of varying lifespan. They emphasized the role of identifying the types, boundaries, and configurations of relationships as a critical component for minimizing the implications of change. Moreover, the authors proposed to employ the DSM method (Design Structure Matrix) that incorporates the two concepts of decomposition and dependencies, and delivers quantitative results. Building components are first categorized into Brand's layers in order to understand the interrelations between them. Then, potential reorganization of the components through clustering is examined. This methodology gives insights into the appropriate layer placement of components and possibilities of introducing new layers, bearing in mind to address the undesired dependencies [54].

Ensuring independence when integrating systems or layers within a building is also highlighted in the literature as a key principle of adaptability that allows components to be removed, replaced, or upgraded without influencing the efficiency of the adjacent systems [3]. In this respect, Geldermans [57] emphasized on providing a clear identification of the components and materials consisting each of the shearing layers while paying a high attention to the intersection zones where demountable and reversible solutions must be contemplated.

Recent decomposition methods propose innovative and efficient strategies that employ the utilization of BIM (Building Information Modelling) and automated tools. Isaac et al. [67] developed software to apply a graph-based decomposition methodology of design into nonrepetitive modules containing components of similar life spans. The methodology then uses a clustering algorithm that is able to interpret BIM data to define an optimal assembly of modules taking into account a minimum connectivity among components. The scholars suggest that standardizing certain interfaces between assemblies of elements allows interchangeability and accurate fit rather than when standardizing the assemblies themselves.

Given all that, the concept of layers delivered essential insights into changing the conventional perception of buildings as static structures to contemplating them as dynamic systems [39]. Understanding the composition of a building and identifying its temporal layers is an important strategy to enable its adaptive capacity by allowing flexibility to shorter-life layers or components and durability to longer-life layers and components [49]. It also ensures an easy access for assessment of component of different life spans to determine their functionality and facilitate their replacement when necessary. The assessment can be achieved through designated access points ensuring that adjacent components to the replaced one are not to be damaged [2,74].

3.3.3. The Circular Economy in Buildings

Building industry is an important pillar of economy, although also a significant contributor to environmental decline. A direct relationship between environmental problems and climate change on one hand and building-related activities and practices on the other has already been proved and acknowledged by the scientific community, raising issues of resource valorization and environmental impacts' minimization to the top of governments' and scientific society's agendas. The intensified pressure on resources that are becoming increasingly scarce has largely contributed to inflated costs overall and creating uncertainty in the short term [75].

In response to the above issues, the Circular Economy (CE) has emerged as a new paradigm of innovative practice for increased sustainability, aiming at decoupling economic growth from resource consumption [58]. The CE concept proposes a systemic shift from the current linear model of economy (take–make–dispose) by adopting a circular model of close-looped value chains. This concept is becoming more relevant for academia, policymakers, and nongovernmental institutions [76,77]. In this respect, the European Commission (EC) released an action plan to promote the implementation of CE in various sectors at different levels. The CE package of EC considers the building sector as one of the five priority sectors to benefit the CE approach by developing new eco-technologies and circular models for all building-related practices and processes [78]. Rethinking building operations based on circular economy principles promises to help the sector to significantly contribute to the mitigation strategies of climate change by addressing issues of resources efficiency and greenhouse gas emissions reduction that are dominant causes of climate change. This can be achieved by setting new design standards, improving materials, and developing new business-model innovations.

Circularity in building is defined as "the dynamic total of associated processes, materials and stakeholders that accommodate circular flows of building materials and products at optimal rates and utilities" [79] (p. 261). In order to facilitate change without loss of materials quality, Circular Building (CB) concept requires adaptable buildings [57,80,81]. Design for Adaptability (DfA) has therefore been investigated as an important enabler for circularity in buildings, which shed the light on concepts of "Open Building" and "Shearing Layers". In this respect, Geldermans [57] affirms that circularity of building products and materials is enabled by adaptable capacity and autonomy over "fit-out" configurations.

Design for adaptability handles issues of buildings obsolescence and redundancy by employing a lifecycle thinking in order to extend the useful life of buildings and building components. This ideology goes hand-in-hand with CE main strategies of "closing the loop" and "slowing the loop", sharing the objective of ensuring to minimize consumption of raw resources and energy input, which reduces the environmental footprint of construction activities related to lifecycle stages. Closing the loop assumes intensified reuse and upcycling of components and materials [82], while slowing the loop aims at increasing the longevity and preserve the value, quality, and efficiency of materials and building products [58] to the highest possible extent.

The current paradigm of building design and construction proved a fundamental system's deficiency represented in tons of CDW (Construction and Demolition Waste) generated from premature and arbitrary demolition practices [65]. This prevalent end-of-life option for buildings and their components is a result of the linear model of production and consumption in the built environment. A circular model of consumption calls for designing buildings for adaptability, which starts with contemplating the end in mind by considering the end-of-life (EoL) scenarios as an essential step within the process of design and takes part in the building as a whole. An important application of DfA in the light of CE is to design multipurpose facilities for shared and alternative use, which seek to retain more value from long-life structures of full lifecycle approach by intensifying their utilization and maximizing their service life [58].

In a circular economy, preserving the value of products for as long as possible is considered a fundamental factor [82]. However, a consideration of long life is not viable without developing an evidence of what the end-of-life scenarios for the building are [49]. Therefore, according to the CE, design for adaptability (DfA) goes hand-in-hand with the other Circular Building (CB) strategies, such as design for longevity and durability, design for disassembly and deconstruction (DfD), standardization and modular design, and Materials Passports (MP), to achieve close-looped systems.

- **Design of Longevity and Durability.** Longevity and durability are also discussed as principles of circularity in the built environment [58] as they imply a decreased demand upon primary resources and energy [83]. However, they strictly adhere to adaptability, because a long-life structure without performing required service would be inefficient [84]. Rather, a long-life structure that is adaptable and having the capacity to change its function, reconfigure, and replace its components in response to emerging needs is a genuine application to circularity on ground. A CE-promoted example in this regard is the development of multipurpose facilities of shared use [58]. These facilities combine both strategies of durability and adaptability by having the capability of switching between different functions while maintaining a structural capacity to support those functions. Moreover, strategies of longevity and durability at a building scale are more efficient than they are at a component or material scale. This is because components can be replaced in a building while they themselves are prone to deterioration and most of recycling processes are downcycling to lower quality for lower value allocations [85,86]. However, components' replacement is mostly disabled in traditional buildings due to the interdependencies and interconnectivities among systems and components that hamper any change, causing significant damage to adjacent components. Still, the durability of the built assets is strongly encouraged by the circular economy [58]. Adaptations in this case can be made by relying on strategies of renovation and refurbishment that aim at extending the useful life of old structures despite being associated with additional material and energy flow. Therefore, designing durable structures should necessarily imply a lifecycle thinking [87] in order to promote retention of end-of-life value (e.g., through selective deconstruction and recycling) and facilitate components replacement. This calls for "Shearing Layers" decomposition of a building system and for the separation of an "Open Building" between the base building of long life and the fit-out/infill that goes through frequent changes. The "Open Building" was examined by Zuidema [88] as the base for CE buildings. Long-life products and building components in the circular economy are considered to require particular attention by promoting synergies between circular economy principles and design for adaptability [57]. The synergies in this case aim at facilitating the direct reuse of durable products by allowing their reincorporation into multiple building systems, which result in products of multiple lifecycles (slowing the loop). Durability and longevity strategies should associate adaptability also in order to accommodate technological upgrade [58].

- **Design for Deconstruction and Disassembly.** Design for disassembly is the most discussed strategy in the discourse of circular building design. It implies that all materials and products used at every level in a building can be neatly disassembled and recovered. By this means, building materials and components have the potential to be reused to their highest extent [89]. In addition, the direct reuse of components contributes to both waste reduction and energy savings [2] and would eventually lead to have multiple buildings with multiple lives (closing the loop) and extending drastically the lifecycle of those components (slowing the loop). Adaptable building is also discussed by the literature as a building in which particular components can be changed in response to external factors, for instance users or surrounding environment [12]. In this respect, Guy and Ciarimboli [74] suggest that designing for disassembly (DfD) goes hand-in-hand with principles of adaptability. Graham [49] likewise lists designing for deconstruction as a key strategy for adaptability. Durmisevic and Brouwer [6] find a strong relationship between adaptability and disassembly through the concept of "Reversible Building". Durmisevic [65] identifies the scale of building reversibility as a key indicator of circular building that can be figured by assessing the adaptive capacity on three levels (spatial, structural, material) and the reuse potential on three levels (building, system/component, element). When components are designed for disassembly and reuse, a further advantage can be created towards sustainability [12], particularly in reducing costs and environmental impact [3]. By this means, building materials and components have the potential to be reused to their highest extent [89]. The REMs pilot model developed within the BAMB project is an important example of a reversible construction system fully designed for disassembly and to support multiple use scenarios. The model had been assembled and disassembled six times with almost zero waste [90]. Design for disassembly is a strategy that depends to a high extent on the integration of components [4] and how easy they are reachable for safe removal and replacement. In this concern, Slaughter [7] argues that minimizing interactions among systems' components and creating specified zones for improved physical access to systems are strategies to further promote adaptability. However, this cannot be achieved in old typical buildings due to the inevitable interactions among systems' components that restrain a safe recovery of components and materials of reuse potential. Still, some other strategies may help to retain maximum possible value from those structures, for example, by performing demolition audits for selective deconstruction. The utilization of demountable connections and prefabricated assemblies is an important enabler for disassembly [2,50], ensuring recovery of materials that are mostly reusable [91] and helping to keep the components of different functions independent from one another [49]. DfD goes beyond the life of a building by addressing the destination of building materials and components [49], accounting for the end-of-life scenarios of buildings at the early design stages [2] that can be an added value to adaptability.
- **Standardization and Modularity.** Standardization is also promoted by the circular economy as an inevitable strategy to promote the reuse of products and materials in multiple structures without essential losses [57]. Meanwhile, modularity has been widely discussed in the literature as an important enabler of adaptability [2,7,8,74,92]. Designing modular components and building products facilitates the process of disassembly and reuse, and therefore the adaptability [93]. They also reduce the costs [49], waste, and ecological footprint. Replicability of modular units allows for design simplicity, which enables physical modification, spatial rearrangement, reconfiguration, repurpose, and expansion. In this respect, prefabricated modular units create an important example providing further value for reduction, reusability, adaptability, and recyclability of their components [94]. Standardization can be achieved at three levels: material, component, and connection. However, each level has a distinct advantage. For example, standardized materials allow for more efficient recycling while standardized components create specific conditions for connections [57]. Connections

in this context grasp major attention due to their importance as vital elements [50,64] in facilitating the change by enhancing the efficiency of modularity through ensuring easy removal and replacement of standardized components [2]. Standardization of connections could be of great value as it exempts the components from being standardized [57]. The use of standardized grids and modularization also facilitates component interchangeability, which is seen as a great enabler of adaptability [7], particularly in commercial office buildings where adaptability is a main stream [4].

- **Material passports for facilitated reuse.** Choosing adequate materials can have a potential influence on adaptability values [2,74]. They are also seen as an important pillar to achieve circularity in building design. Geldermans [57] found that circularity values (thus adaptability values as well) come up when specified intrinsic properties (material and product characteristics) cross with relational properties (building design and use characteristics). What were found to be the right options in the process of materials selection are new or reused biobased or technical materials that can be reused to their highest degree, or a hybrid solution of those two [89]. Those also have to be of high functional quality and of sustainable nontoxic origin [57]. Buildings containing hazardous materials (e.g., asbestos) have less potential for adaptive reuse due to the high risk and elevated costs associated with extraction or containment [2]. Conversely, durable nontoxic materials are important enablers for adaptive reuse projects where they contribute to a prolonged functional life of a building and reuse of its components in other projects [2]. Given all that, new materials must be developed to allow further opportunities for reuse and adaptations of buildings [80]. The use of secondary materials is an important enabler for the waste hierarchy (Reduce, Reuse, Recycle). Yet, the lack of market mechanisms to support recovery is a critical challenge raised by different stakeholders [95]. In addition, concerns about quality of secondary materials and their adequacy for reuse are perceived as additional challenges in this regard, especially when those are salvaged from old buildings. As for the connections, the use of mechanical connections rather than chemical ones helps to ensure a proper level of independence between functions of building layers and components [49].

When talking about materials' circularity, it is important to mention the concept of Material Passports (MP) brought by the concept of Cradle-to-Cradle (C2C). MP is another concept integrated in the frame of Circular Building (CB) research that relies on producing a document reporting all materials and components composing a building [89]. This document describes all characteristics including composition, value for recovery and recycling, reuse potential, and end-of-life (Eol) financial value.

3.3.4. Design for Resilience

Cities and urban areas are constantly coping with critical challenges and complex chronic problems affecting their economic development and social wellness [44]. Climate change and environmental degradation are among the most prominent challenges hitting urban environments and cities where the majority of the globe's population lives and that perform both as the pivots of resource consumption and the hubs of innovation [96]. Among the severe challenges and acute problems that are increasingly confronting cities worldwide and triggered by climate change and environmental degradation, there are natural disasters (earthquakes, floods, etc.) and heat waves. Chronic stresses and gradual trends include accessibility to affordable housing, resources shortage, building obsolescence and redundancy, and rises in average temperatures.

As climate change continues being a reality for the next few decades, there will be an essential need to cope with its impacts and protect our societies and economies from its consequences by planning climate-resilient infrastructure [63]. Addressing the topical challenges posed by climate in an efficient manner requires an enlargement of capacities of built environment systems to respond to uncertainties and future disruptions. In this relevance, the notion of "Design for Resilience" has attracted major attention of both academia and policy makers, being a fundamental goal for cities and built environment [96] in order to address problems related to environmental management and climate-related disruptions [97]. Although resilient design often refers to future extreme climate events, such as natural disasters and climate adaptive survivability in their aftermath, a regular level of resilience is required to cope with chronic and routine stresses [98], which slowly get developed in hazards to the built environment, i.e., buildings obsolescence [99].

Resilience theory suggests tackling the issue of climate change via two directions: mitigation and adaptation. While mitigation targets the causes of climate change by seeking radicalization and diversification strategies to minimize GHG emissions (e.g., reducing resources utilization and energy consumption), adaptation aims at reducing the impact and consequences of climate by increasing the adaptive capacity of systems to absorb its effects while keeping their primary functions. However, both directions are complementary and inherently connected; for instance, mitigation is considered a crucial factor to achieve long-term adaptation [100]. Still, mitigation alone is not enough to restrain disrupting events from happening [97]. Given that, contributing to everlasting urban sustainability and enhanced resilience to climate change calls for joint frameworks integrating both adaptation and mitigation strategies [101].

The concept of adaptability or adaptive capacity is linked to resilience as a key theme in the Sustainable Development Goals (SDGs) (goal N.11 Make cities and human settlements inclusive, safe, resilient and sustainable). Studies reflect a strong relationship between the concept of adaptability and both research directions of resilience (mitigation and adaptation) [102] by considering adaptability as a key concept in achieving resilience [103].

Adaptation to climate change effects has been widely discussed in the literature of adaptability as an important factor contributing to resilience [63]. In addition, adaptive reuse of existing buildings is relevant to the current climate change mitigation agenda due to its ability to recycle resources in place, and to climate change adaptation for its importance in fostering the embodied energy in existing buildings to support climate change adaptation [104].

Resilience can be defined as "the ability of an urban system—and all its constituent socioecological and sociotechnical networks across temporal and spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity" [96] (p. 2). This definition as other literature definitions refers or acknowledges the need to change, which is a common feature with adaptability. However, resilience thinking provides useful understanding for the processes of change. From another perspective, adaptable design treats climate change as an important change factor to be considered for future scenarios. Conejos et al. [14] state "when designing new buildings it is important to be concerned about maximizing the adaptive reuse potential of buildings later in their lives to help mitigate the effects of a changing weather climate plus the volatility of social, economic and environmental conditions" [104] (p. 102). The recognition of resilience as an adaptive capacity in the system is obtaining momentum in developing strategies to address changes in the built environment, particularly predicted changes resulting from climate change [105].

At a building scale, resilience indicates the capacity of a building to preserve its function in the face of environmental disturbances triggered by climate change [106]. A resilient building has been defined as a building that withstands physical damage and either preserves its key functionalities or re-establishes its operations rapidly when a disruptive event hits [107]. Fostering the capacity of buildings to absorb and adapt to the consequences of climate change is becoming crucial, given the huge contribution of the sector to ecological negative footprint [108].

Another attribute shared with adaptability is that resilient design is not a single standard solution or perspective. It can be interpreted through a multifaceted lens that combines proactive and reactive strategies through mitigation and adaptation to address disturbances and external stressors. However, achieving adaptation measures in buildings is challenging due to the nonstatic nature of buildings in the future [4]. Incorporating adaptability and flexibility strategies in building design is an important factor that takes the time dimension into consideration, thus contributing to accommodating both anticipated and unforeseen conditions, and to reducing the vulnerability to future impact.

Key system characteristics that influence the resilience of buildings while fostering adaptability include robustness, redundancy, reflectiveness, resourcefulness or rapidity, longevity, and passive survivability.

- **Robustness:** is the ability to withstand the impacts of stressors and external disturbances without major damage or functional failure. Robustness ensures the durability of the structure so that it is strong enough to cater multiple uses and loading scenarios. Durable claddings and foundations can significantly facilitate adaptability, increasing therefore the potential of conversion over demolition [3]. Overdesigning structural capacity is an enabling strategy for adaptability in buildings [41] and meet future needs [109].
- **Redundancy:** is the capacity spared intentionally to accommodate upcoming disturbance. In this sense, it includes diversity of solutions to address a need or perform a certain function [110]. Redundancy assumes to provide alternatives to support the main functions of a system if the primary solution is disrupted, such as backup generators and multiple water supply systems for a building. The overcapacity of systems and building elements supports changes scenarios, making buildings more adaptable.
- **Reflectiveness:** consists of constantly evolving systems with the ability to modify standards based on emerging conditions rather than pursuing permanent responses to maintain the original state [110].
- **Resourcefulness/Rapidity:** is the capacity of rapidly meeting needs and reaching goals in multiple ways under a certain stress or during a shocking event. Adaptability being a proactive attribute inherited into a system allows for rapid changes.
- **Longevity:** Combining the flexibility of use with the desired structural robustness under certain conditions contributes to high levels of durability and longevity, which are key strategies of resilience that contribute to enhance sustainability as well [107].
- **Passive survivability:** Designing or even renovating buildings to be resilient enough to handle severe weather conditions or climate events relies on the ability to sustain prolonged loss of power via energy load minimization and preserve livable ambience through passive survival strategies. Employing passive measures into buildings contribute to increase adaptability [111]. Key potential methods to raise buildings adaptability to climate change pertain the general design of buildings, optimized ventilation, air conditioning systems, and user attitude [111]. Passive strategies include optimized ventilation, thermal massiveness, passive cooling systems (e.g., passive shading systems) [112], optimal orientation, green surfaces (e.g., green roofs) [86], and renewable energy systems. These strategies allow a building to operate with minimal external inputs [107]. The impact of climate change on buildings makes it more challenging to achieve a thermal comfort without extra energy consumption due to extremely high temperatures [111]. Energy consumption reduction measures contribute to a better behavior of buildings in this case.

Key resilience strategies in buildings that also hold adaptability values are presented in Table 6.

Table 6. Resilience strategies in buildings and their adaptability values.

Strategy	Resilience Feature	Values for Adaptability	Change	Sources
Adaptive skins/shells/envelops (e.g., insulation materials or active renewable elements)	Passive survivability; Reflectiveness	Thermal and performance adaptability	Change in performance	[98,113,114]
Existing infrastructure and structural reinforcement	Robustness	Support future expansions/scalability, e.g., adding stories	Change in size or function	[60,109]
Clear story height	Redundancy; Resourcefulness	Meet floor height requirement of different uses	Change in use	[109,115,116]
Enclosed courtyards	Passive survivability	Adaptability to environmental conditions	Change in performance	[36]
Dynamic facades	Passive survivability; Reflectiveness	Adaptability to environmental conditions	Change in use. Change in performance	[117,118]
Active load-bearing elements	Reflectiveness; Redundancy	Supporting multiple use scenarios	Change in use	[119]
Size and placement of operable windows	Passive survivability	Adaptability to weather conditions	Change in performance	[118]
Renewable energies (e.g., solar collectors and photovoltaic panels)	Passive survivability; Redundancy	Adaptability to environmental conditions	Change in performance	[112,118]
Cavity floors	Redundancy; Resourcefulness	Supporting multiple use scenarios	Change in use	[116]
Double-glazed and triple-glazed windows	Passive survivability	Adaptability to weather conditions	Change in performance	[86,112]
Green roofs	Passive survivability	Adaptability to environmental conditions	Change in performance	[86]

4. Discussion and Open Questions

The utilization of the concept of adaptability in the scope of the built environment usually refers to strategies targeting either (1) designing of new buildings with prospective vision by incorporating adaptability solutions from the early design stages, or (2) redesigning of existing buildings by developing solutions to adapt the existing stock to emerging variables led to their current obsolescence status. The latter case normally considers strategies of retrofitting, rehabilitation, refurbishment, renovations, and adaptive reuse, among others [41,104].

This categorization of adaptability strategies was made clear through Beadle et al. [64] identification of the two adaptability strategies: preconfiguration, which relates to the design stage; and reconfiguration that addresses strategies in the use stage. However, the literature also contains models and decision support tools that address both design and use stages as in [104].

As a matter of evidence, the solutions for enhanced adaptability are more diverse in the case of new constructions than in existing buildings. This is because a large part of adaptability measures and techniques should be thought at the early design stages, then systematically implemented through processes of construction, maintenance, and end-of-life options. Still, some rehabilitation solutions could increase adaptive capacity depending on the scale of intervention and the capacity of the existing building structurally and technically to accept changes. This also depends on the availability of technical data and drawings associated with construction methods and materials applied. Adaptability level in this case is more related to nonstructural elements. In addition, the economic feasibility is in question here.

From the discussion presented in this paper, a number of open questions can be suggested to guide potential future research such as:

1. How can design for adaptability be enhanced in terms of incentives, policies, processes, and stakeholder engagement (process adaptability)? This includes the role of

process flexibility and multi nature enablers along the whole value chain to facilitate implementation of design enablers.
2. What is the role of modern-day technology and intelligent systems in promoting existing design practices, assessing performance, and managing information throughout the whole lifecycle of a building? In this regard, multiple authors emphasized the role of BIM in facilitating the future adaptability of buildings, allowing access to more efficient and accurate information regarding the construction process, materials properties, repair and maintenance, and deconstruction planning [80]. However, some studies still perceive that the use of BIM for such purposes is quite challenging and requires further improvements to achieve further efficiency [67]. Modeling of various scenarios relates to different variables to choose the most efficient adaptability solution, e.g., in [115].
3. To what extent can adaptability be implemented into existing buildings, bearing in mind they constitute a large part of future stock? Extending the life of the existing stock as a hub of anthropogenic materials and embodied energy through more efficient reuse is a global concern derived by increasing demand volatility together with sustainable development agenda [120].
4. Potential future research may also address the temporary adaptations of spaces posed by the actual challenges due to the current COVID-19 emergency. The current challenge of COVID-19 further highlights the necessity of creating buildings of high response capacity to changeable circumstances, environments, and demography [41,121], which should be examined in consideration of other aspects that might affect the new normality of the built environment in post-COVID-19 society.

5. Conclusions

This paper highlights the importance of designing buildings for adaptability as a potential alternative to their obsolescence and redundancy issues, often resulting from the temporal reality of their context and our modern-day challenges. The distinct attributes of adaptability conception in buildings are underlined in consideration of multiple factors that correspond to variables posed by the context and needs, and call for different types of adaptations. The evolution of the concept and its preliminary perception in the built environment are illustrated in view of the open building movement and the later models built upon the principle of separating building structure elements from interior infill. This is followed by the concept of shearing layers and its developments that give a closer look into building configurations and interdependencies between systems and components, and allows for delivery of practical decomposition methods for facilitated understanding of adaptability mechanisms. In order to deliver insights into modern applications, connections with relevant promoting models and complementary strategies to deliver comprehensive solutions are also addressed in light of international trends and global plans, such as the circular economy in buildings and resilience theory within the built environment, where the contribution of adaptability strategies to the process of sustainability is a fundamental criterion to minimize resource and energy consumptions is approved. Moreover, synergies between CE strategies and design for adaptability are examined to develop more comprehensive solutions and create further advantages that cover the full lifecycle of buildings and building components. A special emphasis is placed on the end-of-life phase as a turning point toward achieving circularity in buildings. Further, the contribution of adaptability to achieving more resilient buildings is discussed and multiple solutions of mutual value for adaptability and resilient design are presented. Finally, a concluding discussion is performed and potential research opportunities are presented.

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