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Flexibility and Adaptability: A Review on Assessment Methods and Tools and Their Applicability

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Abstract. *In this paper, the existing methods for the assessment of flexibility and adaptability in buildings are reviewed. These methods have been tentatively proposed for a number of building types / uses - notably for residential buildings - and generally propose sets of indicators, variables and weights that combine into a score of flexibility. In spite of the limited practical applicability of these methods so far, they provide a stimulating approach to greater use and incorporation of the concepts and strategies of flexibility and adaptability, aiming at an increased performance of buildings.*

Keywords: *Flexibility; Adaptability; Buildings; Assessment methods; Performance.*

1 Introduction

The promotion of flexibility in buildings is a commonly applied strategy in various uses, with the aim of facilitating space reconfiguration and extend the lifespan of buildings. The theoretical foundations for incorporating flexibility in construction were initially established in the 1960s by Habraken (1972), and further developed with the creation of Stichting Architecten Research Foundation (1965). This approach, along with a reconsideration of design processes and long-term building performance, can be observed in the works of Eldonk and Fassbinder (1990), Kendall and Teicher (2000), and Schneider and Till (2007).

When flexible use is proposed in the design process, it increases the likelihood that the building will be able to meet changing demands throughout its lifespan. In fact, by implementing the principles of flexibility and adaptability, as mentioned by Gijsbers and Lichtenberg (2012), technical modifications can be executed with optimized costs and efforts, making renovations and conversions financially advantageous as well.

Different strategies can be applied to an architectural project to make it flexible and/or adaptable, but their application should be context-specific. Not all strategies are compatible with certain architectural typologies or uses; for example, solutions used in office buildings may not be suitable for a single-family residence.

The objective of this study is to contribute to the systematization of concepts related to spatial flexibility and adaptability. It seeks to identify the types and facilitators of flexibility, as well as present studies and methods related to the evaluation of flexibility and adaptability in different types/uses of buildings.

2 Background

2.1 Spatial Flexibility and Adaptability

The concept of flexibility and adaptability in buildings has been extensively discussed by various authors. Costa et al. (2017) state that "multiple definitions are adopted by different authors, and there is even some overlap between the terms flexibility and adaptability, sometimes used interchangeably and sometimes treated as distinct concepts."

Flexibility can be defined as the ability of a building to accommodate transformations that allow for various forms of occupancy over time or simultaneously, as well as different interior distributions, effectively responding to the current and future needs of its users. According to Logsdon et al. (2019), it encompasses "the potential to make changes and adjustments before occupancy, as well as during the period of use." Farias (2019) describes flexibility as "the possibility of physically transforming the space in order to better and more diversely meet the users' needs."

Adaptability, as described by Schneider and Till (2007), refers to the "quality of being adaptable; the capacity for adaptation" of a building, indicating its ability to adapt to various proposals and uses, without major changes. It represents the ability to respond to a "wide range of events occurring in different circumstances". Adaptability is also sometimes referred to as passive flexibility.

Freitas (2020) suggests that flexibility and adaptability can be seen as potential attributes of a building, only manifested when demanded by those who seek to use it in different ways or transform it. In addition to meeting immediate usage needs, a flexible and adaptable space empowers decision-making regarding its use and spatial configuration throughout its lifespan, as long as solutions are adopted that do not compromise the feasibility of future adaptations.

2.2 Extending the Lifespan through Flexibility

A conventional building is typically designed with a lifespan of approximately 50 years to 80 years, depending on the construction type (i.e. timber vs. concrete). However, incorporating flexible elements in the design decisions can significantly extend its lifespan up to 100 years (Finkelstein, 2009); and there are countless examples of buildings of more than a century-old still is use: “such as the Pantheon in Rome (in use for around 1900 years) or the Arena in Verona (from the year 30 to the present day)” (Gaspar, 2022). Kronenburg (2007) emphasizes that different strategies are employed in different types of buildings, leading to the question of identifying the most critical elements in facilitating flexibility. Although categorizing such diverse solutions may be challenging, common factors can be identified.

Barbosa (2016) enumerates fourteen elements that facilitate flexibility in residential buildings based on studies by Kronenburg (2007) and Finkelstein (2009) (Table 1). Finkelstein (2009) further identifies different types of flexibility (Table 2) and notes that a single project can exhibit multiple types. These types can be classified based on two fundamental factors: a) "intrinsic form flexibility", referring to projects that adopt a neutral architecture, allowing room for user interpretation – previously referred to as adaptabilty, and b) "projected form flexibility," pertaining to projects that provide flexibility options for users, with the design itself anticipating possible changes throughout the building's lifespan.

The integration of flexible elements and the consideration of various types of flexibility not only enhance the immediate functionality of the building but also empower users to make informed decisions about its use and spatial configuration throughout its lifespan, without compromising future adaptability. These concepts lay the groundwork for creating buildings that can effectively respond to evolving needs and maximize their longevity.

Table 1. Elements of design facilitating flexibility, Barbosa (2016) adapted from Finkelstein (2009).

Elements of design facilitating flexibility		
	Key element	Description
1.	Independent structure	Allows for the free placement of walls since they do not need to bear structural loads.
2.	Modular Structure	Modulation aims to coordinate the dimensions of building components, ensuring flexibility in the combination of elements, precise definition, and ease of production.
3.	Light walls and partitions	They can be made of different materials such as glass, plaster, wood, etc. They must meet certain requirements, such as satisfying acoustic and visual privacy needs.
4.	Adjustable / movable partitions	They function as agents of integration and separation of spaces according to given requirements. This mechanism provides different alternatives for the use and distribution of activities within the space.
5.	Furniture as a partition	The use of furniture as partitions to integrate, separate, and define spaces at any time, independently of the construction.
6.	Vertical circulation cores (within the unit)	Vertical circulation located in a single core.
7.	Bathroom/kitchen cores	The grouping of spaces / uses that require infrastructure installations such as plumbing, sewage, and electrical systems, with the aim of creating a core.
8.	Shafts for infrastructure	Provision of hollow spaces, between walls that house vertical installation ducts. Also enabling expansion of infrastructure systems based on changing demands.
9.	Free facade	The independence between facace and structure, allows for the former to be designed and later changed without constraints.
10.	Sun-shade grids, brise-soleil, balcony on the facade	Grids: the idea of organization and systematic arrangement; sunshades as elements that organize the facade and control solar radiation. Balconies offer greater freedom for usage and allow for different activities.
11.	Open space without internal divisions	Spaces without internal divisions when handed over to the end user. In certain buildings types (office builgings) it is common to handle a shell and core building, to be adapted by future users.
12.	Raised technical floors (suspedended ceilings)	Removable panels supported by an adjustable height structure to create open spaces for installation requirements.
13.	Built-in cabinets	Any type of furniture that serves the function of storing belongings and has been preconceived in the design.
14.	Terrace	When delivered empty to the user, terraces allow for their adaptation by endusers or for the installation of technical equipment and infrastructural systems.

2.3 Adaptive Capacity of a Building

Schmidt and Austin (2016), citing Cowee and Schwer (2012), described adaptability as the ability of a building to adjust or be adjusted to new situations and react quickly to new circumstances with minimal effort and justifiable cost. Adaptive capacity refers to the intrinsic characteristics that allow a building to maintain its functionality through changing requirements and circumstances, sustainably throughout its technical life cycle (Geraedts, 2016), without major alterations to their structure and lay-out.

Studies show that solutions with a high degree of adaptability are more efficient in the long run, as adaptations may occur multiple times during a building's lifespan (Gijsbers et al., 2012). This capacity is related to the design and construction processes that aim to facilitate future changes by the user. The Theory of Supports, developed by Habraken (1979), addresses the fundamental distinction between what he called "structural supports and detachable units" of the building. The concept is based on layered construction, which allows for the anticipation of future scenarios enabled by the chosen support system (structure and services) in the design (Costa et al., 2017).

The configuration of building components in relation to their hierarchy, durability, function and likelihood of being adapted is vital for the project's lifespan. The use of principles that implement stratification, with independence of durability layers, where the parts of the construction that will be more frequently adapted can be reached with minimal interference for other layers (Brand, 1994), facilitates their adaptation over time and allows for meeting user needs.

Table 2. Flexibility types, defined by Barbosa (2016), adapted from Finkelstein (2009).

Felxibility types			
Factors	Symbol	Characteristics	Description
Íntrinsic flexibility	A1.	Neutral spaces; possibility of space transformation;	Projects with spaces with dimensions and configurations (neutral form) open to different uses. Not over specified to or designed to meet a single use.
	A2.	Initial flexibility, alternatives to choose from;	In this group, there are projects that offer "floor plan flexibility" for the end user.
Projected form flexibility	B1.	Multiple possibilities for spatial distribution (layouts);	It occurs where flexibility is a design premise, and the user is given alternative options for activity distribution.
	B2.	Changes throughout the day/night;	It allows for changes in spaces according to the time of the day (day or night).
	B3.	Unfinished projects;	These spaces are delivered to the user in an unfinished state, meaning that only the structure is provided, and it is up to the user to arrange the components as desired.
	B4.	Expandable projects;	They are design methods with open endings that allow the user to increase the area after delivery.
	B5.	Possibility to subdivide/integrate spaces;	The possibility to subdivide and/or integrate spaces through the use of facilitating elements such as sliding doors, pivot doors, or even through specially designed furniture. Regular rectangular spaces favour such possibility.

3 Methods for Assessing Flexibility and Adaptability in Buildings

A number of models and tools have been developed over time to assess and evaluate the flexibility and adaptability of buildings. Geraedts (2014) conducted research on available methods and instruments for assessing adaptive capacity in the literature. The author concluded that while much attention is given to the importance of flexible and/or adaptable construction, few concrete and practical estimation tools have been developed for this purpose. The identified instruments at the time generally only outlined the aspects to be evaluated.

Rockow et al. (2018) conducted a systematic review of models and tools for assessing building adaptability, aiming to identify and classify the current state of the art in terms of adaptability evaluation methods and decision support tools available for building adaptation. The authors classified the models based on the focus: a) adaptation decisions for existing buildings; b) design of new buildings for future adaptation; and c) understanding adaptation throughout a building's life cycle. Additionally, they examined the types of resources considered and the degree and type of model validation. A summary of the evaluated models and tools is presented below (Table 3). A detailed discussion of each model is beyond the scope of this paper though.

According to the authors, models focusing on the assessment of existing residential buildings are more advanced and validated compared to other types of models, making them more suitable for professional application. They also highlight that the modeling of adaptability in buildings is still in its early stages, and quantitative modeling based on data is an area that presents gaps and requires further development in future research. Both model reviews reinforce the need for practical instruments that can be applied for quantitative analysis of buildings.

Table 3. Summary of the models evaluated by Rockow et al. (2018).

Model	Focus			Main characteristics		Validation		
	Initial Design	“Adaptable?” decision point	Building life cycle	Physical	Context	No	Case studies (n<100)	Data base (n>100)
ARP		x		x	x		x	
adaptSTAR	x			x	x		x	
iconCUR		x		x	x		x	
CLD			x	x	x	x		
FLEX 4.0	x			x			x	
PAAM		x		x	x		x	x
LBF	x			x		x		
ABD	x		x	x	x	x		
Conversion Meter		x		x	x		x	
McArthur and Jofeh		x		x	x		x	

Source: adapted by the authors from Rockow et. al (2018).

3.1 Analysis of the FLEX 4.0 model for flexibility assessment

Considering the models identified by Rockow et al. (2018), the tool developed by Geraedts (2016) to determine the adaptive capacity of buildings, namely FLEX 4.0, was selected for a more in-depth analysis in this study. The choice can be explained by the ease of use and implementation of the method, as well as the applicability to different types/uses of buildings. The tool aims to evaluate and identify characteristics that enable a building to maintain its functionality despite changes in requirements and circumstances throughout its technical life cycle in a sustainable and economically viable manner. It employs indicators related to flexibility and adaptability, as well as defines and quantifies the degree of adaptive capacity. The FLEX method was developed through bibliographic research, resulting in basic summaries of flexibility indicators and their mutual relationships. Subsequently, experts involved in project development were consulted to evaluate these indicators. Finally, a report titled "Buildings with Future Value!" (A&B, 2014) was proposed, presenting 147 adaptability criteria (evaluation indicators). The research and expert panels enabled the establishment of indicator relationships. However, the extensive nature of the list posed challenges for its application, and at that time, the list did not have a classification based on importance or an interrelation between different criteria.

In 2015, additional research led to a renewed evaluation method with 83 indicators grouped into five layers representing different life cycles, known as FLEX 2.0. The method was applied in two research projects to identify indicators applied in practical project development.

Carlebur (2015) conducted a study focusing on different types of school buildings in the Netherlands, aiming to relate adaptability indicators that determine the adaptive capacity of buildings and develop a method for evaluating these buildings and their projects in terms of adaptive capacity. The second study, conducted by Stoop (2015), focused on office buildings and aimed to develop a method for determining the future value of office buildings in a manageable version with a specific focus on the adaptive capacity component. The research resulted in a list of 35 indicators characterizing the adaptive capacity of office buildings.

Based on the main conclusions and recommendations from the studies conducted by Carlebur (2015) and Stoop (2015), Geraedts et al. (2016) implemented the preliminary structure of FLEX 3.0, developing a more accessible and practically applicable model. The final results led to a new structure, forming the latest version of the evaluation tool called FLEX 4.0 (Geraedts, 2016). This version comprises 44 key performance indicators of flexibility and their associated evaluation values. The authors also emphasize what they consider to be the 12 generally applicable indicators of flexibility performance, regardless of the type of property being evaluated (Table 5).

Table 5. 12 Flexibility indicators, assessment values for each indicator and the weighting by Geraedts (2016).

Layer	Flexibility Performance	Assessment Values	Weighting
1. Site	1. Expandable site/ location	1. No, the site has no surplus of space at all (bad) 2. 10-30% surplus (normal) 3. 30-50% surplus (better) 4. The site has a space of more > 50% (best)	1
2. Structure	2. Surplus of building space/ floor	1. Not oversized (bad) 2. 10-30% surplus (normal) 3. 30-50% surplus (better) 4. > 50% oversized (best)	4
	3. Surplus of free floor height	1. < 2.60 m (bad) 2. 2.60 – 3.00m (normal) 3. 3.00 – 3.40m (better) 4. > 3.40m (best)	4
	4. Acess to building	1. Entrance/core separated (bad) 2. Entrance/core combined (normal) 3. Building divided in different wings (better) 4. Centralized and separate (best)	2
	5. Positioning obstacles / columns	1. Adaptation obstructed (bad) 2. <50% is obstructed (normal) 3. <10% is obstructed (better) 4. No building space is obstructed (best)	3
3. Skin	6. Facade windows to be opened	1. No or < 10% windows can be opened (bad) 2. 10-30% (normal) 3. 30-80% (better) 4. 80-100% (best)	1
	7. Dayligth facilities	1. Dayligth factor <1/20 (bad) 2. Dayligth factor 1/20 - 1/10 (normal) 3. Dayligth factor 1/10 - 1/5 (better) 4. Dayligth factor > 1/5 (best)	2
4. Facilities	8. Customisability / controllability	1. Monofunctional use (bad) 2. Limited customizable (normal) 3. Partly customizable (better) 4. Easy customizable (best)	3

	9. Surplus of facilities shafts	1. Shafts and ducts have no surplus at all (bad) 2. 10-30% surplus (normal) 3. 30-50% surplus (better) 4. Surplus of space more than 50% (best)	4
	10. Modularity of facilities	1. No facility is divided (bad) 2. 1 of the 4 facilities is divided (normal) 3. 2-3 of the 4 facilities are divided (better) 4. All of 4 facilities are divided (best)	2
5. Space	11. Distinstion beteween support - inflill	1. <10% of the building (bad) 2. 10-30% of the building (normal) 3. 30-50% of the building (better) 4.> 50% of the building (best)	4
	12. Horizontal acess to building	1. Single access (bad) 2. Duble access (normal) 3. Access by a core and corridor (better) 4. Access by a core and external gallery (best)	3

Source: Geraedts (2016).

Performance indicators are assigned scores calculated based on the physical characteristics of the building and their relative importance for adaptability. The criteria (or "key indicators") considered in the tool are organized around the building layers established by Brand (1994) and focus on the physical characteristics of the construction. Contextual features of the building are not taken into account.

Each indicator has four evaluation values ranging from 1 (Worst) to 4 (Best), with intermediate values of 2 (Poor) and 3 (Good). When evaluated, each indicator generates a score (evaluation x specific weighting for the 12 indicators), which, when summed, results in the total flexibility score. The cumulative value obtained determines the class, categorized into score intervals corresponding to different levels of flexibility, as presented in Table 6.

Table 6. Score Range and Flexibility Class Defined by Geraedts (2016).

Flexibility Classification and Scores		Score
Level 1	Not flexible	12-48
Level 2	Poor or Limited flexiblility	49-85
Level 3	Moderately flexibility	86-122
Level 4	Very flexible	123-159
Level 5	Excellent flexibility	160-192

Source: Geraedts (2016).

Several versions of the application that investigates the adaptive capacity of buildings have been developed since 2014. However, further studies are needed to evaluate the implementation of this tool in practice, based on case studies, in order to develop projects with adaptability in mind and to assess the adaptability provided by buildings (Geraedts, 2016).

4 Conclusions

The concepts and reflections presented in this study are based on the premise that, in addition to meeting immediate usage needs, flexible and adaptable spaces can empower decision-making regarding usage and spatial configuration throughout the life cycle of buildings, provided that solutions are adopted that do not compromise the feasibility of future adaptations.

The review of definitions and evaluation models regarding flexibility and adaptability reinforces the need for practical tools that can be applied for quantitative analysis of existing buildings and assist in the development of future projects. The scarcity of validation of the models is observed as well as a lack of comparative application between different building uses.

Identifying and assessing the types and elements that facilitate spatial flexibility and their adaptive capacity can contribute to the improvement of architectural designs, as well as promote the increased use and incorporation of flexibility and adaptability concepts and strategies in different types of buildings, leading to enhanced performance.

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