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FLEXIBLE AND ADAPTIVE BUILDINGS SINCE EARLY DESIGN STAGE

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The sustainability concept implies a long-term vision. People's life is constantly changing, and buildings should cope with it. Buildings should be able to adapt to new requirements whenever needed. Nevertheless, conventional buildings are not design do be modified, leading to unnecessary and premature demolition. Preserving built heritage, promotes the population wellbeing and cultural identity. Thus, a building's flexibility potential can have major impact on society, environment, and economy. In this since, building design should include flexibility concerns to allow buildings to adjust to new requirements easily, hence extending their life cycle.

The concept of adaptability is already considered in several building sustainability assessment (BSA) tools; however, it is not common practice, nor meant to all types of buildings. In addition, existing BSA tools are only applicable to later design stages not being able to aid designers establish and accomplish adaptability goals. In this sense, this paper aims at presenting a method to support decision-making at early design stages, fulfilling this gap, by describing how adaptability can be ascribed in BSA tools at early design.

The method allows establishing objectives and comparing alternative design solutions to support electing the solution with the better performance, regarding the established goal. It was found that the method should include the following two sub-indicators regarding adaptability: (i) flexibility provision and

(ii) adaptability capacity. The first, deals with design strategies to accommodate change, through the transformation capacity, while the second quantifies the space availability for change, following the open building concept, evaluating the percentage of adaptable area. When considered at early design, these aspects allow extending the buildings' life cycle, reducing their environmental impact. Increased transformation capacity means that buildings can better accommodate new requirements, improve their dismantling potential, thus enabling replacement, reuse, or recycling towards sustainable and resilient buildings.

1. INTRODUCTION

Building should embed change, by being planned to reuse and reconfiguration, enabling adaptation to new requirements, fostering the sustainability of the built environment. Adaptability can be defined as the ability to change to suit overtime new requirements, considering spatial, structural, and service alteration strategies (Schmidt *et al.*, 2010). By all its implications, adaptability is essential to achieve sustainability, assuming that a building is as more sustainable as its transformation capacity increases (Figure 1).

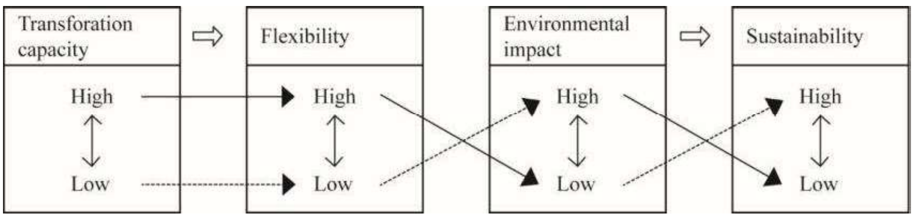

Figure 1. Relation between building conversion capacity and sustainability (Durmisevic, 2006)

Buildings are typically seen as static rather than evolutive, capable of absorb change. This often leads to premature demolishing actions (Durmisevic, 2006). As lifestyle patterns change throughout a lifetime, buildings should be able to cope with that being able to adapt and accommodate new requirements. Readjusting the buildings to new requirements would help attaining the EU requirements to reduce the construction and demolition waste in 70% by 2020 (EU, 2008). By preserving and adapting buildings, it is possible to extend their life cycle, this reduce their environmental impact, reduce the overall embodied energy, and waste production (Conejos *et al.* 2014). Also, flexible and adaptable buildings allow enable up-recycle into urban regeneration projects. Preserving built heritage benefits cultural identity, sense of belonging, and even has economic welfares, as the tourism boosts local economies, which is often driven by the cultural heritage of the city (Tweed & Sutherland, 2007). If flexibility is foreseen during design, maintenance and refurbishment operations will have its time and cost reduced (Gosling *et al.*, 2008).

In this sense, to promote buildings adaptability, transformation capacity and flexibility issues should be considered right at the early stages of a building design. During early design the costs of implementing any measure can be lowered, and building's performance can be improved (Kovacic & Zoller, 2015), being easier and cheaper to establish sustainability goals, whether they relate to adaptability or not. So, as soon as adaptability goals are established in the design process the easier and simpler it will be to erect a adaptable and sustainable building.

2. OBJECTIVES

Baring this in mind, the major aim of this paper is to briefly present a novel method to aid early sustainable design decision-making, and specifically present how adaptability can be considered early in the design within this method. Therefore, two sub-indicators calculation procedures are described "flexibility provision" and "adaptability capacity".

3. BUILDING ADAPTABILITY DESIGN

The concepts of space adaptability and flexibility, emerge as a mechanism to address the lack of a permanent link between the user, changing constantly, and the designer. Devices that provide the desired space availability and the composition of the building allow accommodating different modes of use in situations that are limited at the outset. Thus, the flexibility in its various forms aims primarily at freeing the building sector of the negative aspects, so that the needed multi-functionality is achieved. Therefore, the concept of flexibility can be subdivided into two major groups: the initial flexibility and continuous flexibility.

The initial flexibility is considered to encompass the mechanisms capable of offering the possibility of choosing the desired spaces before the occupation of the house, allowing the active participation of its inhabitant and promoter in its design. As a variation of these cases, one adds the devices that promote the expansion of the house from an initial modular core, such as an evolutionary organism. This flexibility allows the existence of a constant flexibility, in which the space already occupied, through other organisational devices, maintains a character of versatility and polyvalence, integrated in a global identity of the whole at a spatial level, marked by a precise balance between stability of shapes and fluidity of space.

The concept of continuous or permanent flexibility, as described by the authors, would be the desired response to the possibility of modifying the envelope over time, being sub-divisible into three concepts: mobility, evolution and elasticity (Eleb-Vidal *et al.*, 1988). Mobility implies a rapid change of spaces according to the hours and activities of the day: evolution presupposes the long-term modification of family transformations; and the elasticity corresponds to the modification of the living surface by joining one or more compartments.

Adaptability is another way to understand the flexibility. The adaptive building admits many different functions at present and in the future. It also allows for the possibility of the change of use (Maccreanor, 1998). So, regarding the concept of adaptability, it is important always take into account the capacity of a building to absorb different uses during its lifetime, and on the other hand, the possibility of using the same space for different functions during all the use phase.

In this regard, adaptability can be defined as the capacity to adjust and suit new situations, accommodating new demands regarding space, function, and componentry to fit a purpose, value, and time (Schmidt *et al.*, 2010; Till & Schneider, 2005; Manewa *et al.*, 2013).

The life requirements of a building change throughout its life cycle, especially when dealing with a residential building. A person's living situation changes a few times over the years, and houses should cope with it. This way, houses should function accordingly, so that people would not need to move just because their life requirements have changed (Bokalders & Block, 2010).

To ease future modifications, total or partial dismantlement or deconstruction, as well as materials and components recovery, reuse, and recycle, Design for Disassembly (DfD) concept arose (Guy & Ciarimboli, 2008; Webster, 2007). DfD supports circularity in the built environment, pursuing the target of closing materials loops as it remains one of the most challenging efforts of sustainable buildings (Kibert, 2013). Durmisevic (2006) developed a method to assess the building's transformation capacity based on its disassembly potential. Davico (2013) presented an evaluation method to evaluate the level of a project's flexibility.

The Open Building concept, proposed in 1961 by John Habraken, states that buildings can be designed in separate layers to allow optimal layout freedom and modifications (Dekker, 1998). Habraken (*in* Cuperus, 2001) defended that such layers should accommodate unknown future changes, by having different levels: tissue, support, and infill, and the urban fabric, containing base buildings with their fit-outs. With this in mind, Guy & Ciarimboli (2008) created a terminology: Site – Structure – Skin – Services – Space Plan – Stuff, for building layers that could have different service lives, flexibility and performances and that should be accounted in building design.

The aspects that most affect the building flexibility are implementation, form, structure and size, circulation and technical systems positions, and usable areas size (Davico, 2013; Živković and Jovanović, 2012). it is also important to consider the level of separation of the buildings' components and materials and their function, as it can also affect the buildings transformation capacity. Nevertheless, Bokalders & Block (2010) defend that a building should not be too flexible, as otherwise it could jeopardise its benefits.

Adaptability is often considered within BSA methods by (i) ease of disassembly and deconstruction, (ii) spatial structure (iii) indoor height clearance, (iv) accessibility of utilities cables and conducts and, (v) modularity, especially for office buildings (Bragança *et al.*, 2016). However, the international standards as ISO 21929-1:2011 and EN 16309:2014, recommend addressing adaptability also through: (i) individual users, (ii) change of user, (iii) technical aspects and, (iv) change of use (ISO, 2011; CEN, 2014). EN 16309:2014 stated the following as measures to evaluate the adaptability potential of a buildings:

- Minimisation of internal load-bearing-elements (columns, internal walls);
- Ease of demolition/demountability of internal building elements;
- Redundancy in load-bearing capacity;
- Accessibility/demountability of pipes and cables;
- Provision of space for additional pipes and cables required for a change of use;
- Provisions for possible future equipment (e.g. elevators).

Accordingly, the inclusion of adaptability concerns is crucial for to attain a sustainable built environment. In this way, adaptability should be included in the building sustainability assessment methods, enabling to reward its potential to expand the building's life cycle, reduce its environmental potential and promote the wellbeing of its inhabitants and community.

4. RESEARCH METHODODOLOGY

The development of the adaptability indicator evaluation process was carried out within the development of the novel decision-supportive method for sustainable residential buildings early design. The research methodology adopted to the development of such a method, was the following:

i. literature review;
ii. analysis and evaluation of existing BSA tools;
iii. distribution of a questionnaire;
iv. framework proposal and;
v. case-study validation.

The aim of this paper is not to thoroughly present the development of these five stages. Instead, it presents the development of the calculation procedure of the adaptability indicator, carried out within the elaboration of the decision-supportive method for sustainable residential buildings early design.

The steps (i) to (iii) revealed the need to consider adaptability aspects in the method being developed. In this steps, existing literature regarding building sustainability was reviewed, a throughout analysis of BSA methods was carried out and a questionnaire to designers was implemented. This latter aimed at gathering the designers understanding about sustainability and which aspects they consider relevant to be included in a building design. The three steps poited out that adaptability, spatial efficiency, ease of disassembly, reuse, recycling, and durability contribute the building's environmental impact, but are not covered by legal requirements (Gosling *et al.*, 2013). In the questionnaires the designers considered adaptability aspects to be relevant to the buildings' sustainability (Andrade, 29017). Thus, corroborating the need to include adaptability features in the developing tool.

After, the sustainability matrix to be included in the developing tool was established (stage iv). This matrix included one adaptability indicator, subdivide into two sub-indicators: (i) flexibility provision and, (ii) adaptability capacity. To develop the evaluation procedure for these two sub-indicators, stages (i) and (ii) of the research method where repeated, reviewing literature about the topic and analysing the BSA tools evolution procedures for adaptability. The approach focused on identifying existing research for promoting and assessing the building's functionality aspects and how this was already dealt with in BSA tools.

As considering early design, the calculation procedures should be developed according to the following premises: easy to assess yet, enable the comparison of alternative solutions performance, and acknowledge the efforts of the designers and their established goals. To cope with this, two approaches were followed: i) descriptive and, ii) indicative. In the descriptive path, designs can select the goals to accomplish, verifying to which indicative performance level does it corresponds to. In the indicative path, it is the other way around, meaning that designers can first select the performance level to attain and be retrieved with the measures to be implemented as to achieve the established goal. With the project evolvement, more accurate assessments and verification can be carried out, if desired, to implement and validate the indications given with the developing tool.

5. ADAPTABILITY AT EARLY DESIGN

According to Durmisevic (2006), only the flexibility of the buildings' assembly can be considered during early design, not its functional decomposition, as this can only be worked on after all necessary aspects have been considered. Different authors, as Davico (2013) or Durmisevic (2006) proposed methods to evaluate and design flexible and adaptable buildings, although in different ways. Davico (2013) proposes a set of possible design solutions, rather than a method to design any solution, while Durmisevic's (2006) model is too complex for a straightforward and quick analysis. Moreover, both methods do not follow directly the recommendations from EN 16309:2014.

The calculation procedures developed for both sub-indicators were based on the methods presented by these two authors, as presented next.

5.1. Flexibility provision

The flexibility provision sub-indicator intends to evaluate the design strategies adopted to accommodate change, promoting future-proof homes and ease of disassembly. Based on the Durmisevic (2006) model, its evaluation is achieved by calculating the transformation capacity (TC). A higher TC eases the ability of the building to accommodate new requirements and its disassembly potential enabling reuse and recycling of components, and aiding reducing the building's environmental impact.

The method was simplified to ease its applicability to early design stages, by diminishing the number of input levels and by using only the dependency nodes in the aggregation process. This occurred by withdrawing aspects that do not directly affect a more functional and easily convertible building and by prioritising the aspects already considered by BSA tools (OpenHouse, 2010; Barbosa *et al.*, 2013). To cope with the simplification, the weights were redistributed according to the relative importance of each of the remaining aspects. Nevertheless, if one is attempting to achieve a high TC, the use of the full method is recommended in later stages of the design, when more data is available.

The evaluation procedure consists of a qualitative approach through a check-list, rewarding the designers' efforts to achieve a high TC, according to Table 1 input level column (level 0). To each checked item, a grade is given following the weights from Durmisevic (2006). Level 0 (input level) regard the effort to be checked, which is then aggregated to Level 1 by using the Equation 1. The aggregation process from Level 1 to Level 4 is carried out with the weighted sum method, using the weights given in Table 1.

$$D_{sa_k} = \frac{\sum_{i=1}^{n} g_i}{n} \tag{1}$$

Where D_{sak} is the result of the Disassembly sub-aspect *k; g_i*: is the grading from the independent variables *i* selected from Level 0 and; *n* is the number of *i* selected.

Table 1. Aspects considered with flexibility indicator and corresponding grading

Level 3 Transformation/ Disassembly criteria	Level 2 Disassembly aspects to TC		Level 1 Disassembly sub- aspects		Level 0 Input level	
Material Levels [0.5]	Functional decomposition	0.67	Functional separation	0.56	Separation of functions	1
					Integration of functions with the same life cycle into one element	0.6
					Integration of functions with the different life cycles into one element	0.1
			Functional dependence	0.44	Modular zoning	1
					Planned interpenetration of installations and load-bearing elements	0.8
					Unplanned interpenetration of installations and load-bearing element through a free zone	0.2
	Systematisatio n	0.33	Structure and materials	0.5	Components	1
					Elements/components	0.8
					Elements	0.6
					Materials/elements/com ponents	0.4
			Clustering	0.5	Clustering according to function	1
					Clustering according to material life cycle	0.6
					Clustering for fast assembly	0.3
Interfaces [0.5]	Assembly	0.33	Assembly direction based on assembly type	0.56	Parallel – open assembly	1
					Stuck assembly	0.6
					Base element in stuck assembly	0.4
			Assembly sequences regarding material levels	0.43	Component/component	1
					Component/element	0.8
					Element/component	0.6
					Element/element	0.5
					Material/component	0.3
	Interfaces [0.5]	0.67	Type of connection	0.5	Accessory external connection	1
					Direct connection with additional fixing devices	0.8

Level 3 Transformation/ Disassembly criteria	Level 2 Disassembly aspects to TC		Level 1 Disassembly sub- aspects		Level 0 Input level	
Interfaces [0.5]	Interfaces [0.5]	0.67	Type of connection	0.5	Direct integral connections with inserts	0.6
					Accessory internal connection	0.4
			Accessibility to fixing and intermediary	0.5	Accessible	1
					Accessible with extra operations causing no damage	0.8
					Accessible with extra operations causing reparable damage	0.6
					Accessible with extra operations causing partly damage	0.4

Table 2 presents the indicative performance levels for the flexibility provision, which follow the Durmisevic (2006) performance categories.

Table 2. Indicative performance levels for flexibility provision

Level	Description	
Level 1	TC ≤ 33%	Low transformation capacity
Level 2	33% < TC < 67%	Medium disassembly capacity
Level 3	TC ≥ 67%	High disassembly capacity

5.2. Adaptability capacity

This sub-indicator aims at measuring the space that is available to be changed according to the inhabitants' requirements. To do so, it quantifies the Global Adaptable Space (GAS) according to equation 2 (Davico, 2013), i.e., the percentage of built area available to be transformed. Then, the adaptable area is given by the difference between the net internal area and the internal fixed area (area that cannot be changed).

$$GAS = \frac{NIA - IFA}{GEA} \tag{2}$$

Where *NIA* is the net internal area (m^2), *IFA* is the internal fixed area (m^2) and, *GEA* is the gross external area (m^2).

The evaluation results can be achieved with one of approaches already described, descriptive or indicative. With the descriptive, the adaptable area is known, the GAS value is automatically obtained and the indicative performance level is given (Table 3). Following the indicative path, GAS can be estimated according to the intended performance level, which uses the NIA estimation from another indicator – space efficiency (Andrade, 2017). Table 3 gives the indicative performance levels, which were obtained applying the factor four rule (Weizsäcker, *et al.*, 1998) to the ratio NIA/GEA.

Table 3. Indicative performance levels for adaptability capacity

Level	Description
Level 1	GSA < 25 % of NIA/GEA
Level 2	25% ≤ GSA < 50 % of NIA/GEA
Level 3	50% ≤ GSA < 75 % of NIA/GEA
Level 4	GSA ≥ 75% of NIA/GEA

In the cases where data is scarce, it is possible to estimate IFA based on the area quote assigned to kitchens and bathrooms (Davico, 2013). Typically, 9.64% of the NIA of single-family buildings is occupied by bathrooms and 13.14% concerns household activity spaces such as kitchens, pantries, utility rooms, etc. (Oliveira, 2012). This means that 22.78% of the NIA can be considered as fixed area, remaining 77,22% of NIA available to be transformed. Ideally, for a building to be fully adaptable all its net internal area should be able to be adapted.

When desired, design alternatives can be tested and their performance levels compared, to verify which fits adaptability design goal.

6. CONCLUSIONS

Considering sustainability concerns at a building's project early design is key to achieve a sustainable built environment. If sustainability goals are established early, the chances to succeed in implementing them are higher and at lower costs. Therefore, tools and methods are needed to support sustainable decision-making during the design phases.

While several sustainability concepts are well-known and already considered, such as energy efficiency or low impact materials, adaptability is often overlooked. However, a building that is adaptable can live longer, have a lower environmental impact and be in line with the needs of its users, promoting their life quality and comfort. Additionally, by preserving built heritage and adapting it to new requirements, the sense of belonging is boosted, preserving cultural heritage and local economy. Although the existing BSA methods can consider adaptability potential, these are not useful nor applicable at the early design stages of a building.

This paper presented how adaptability can be evaluated within a novel decision-supportive method for the early sustainable design of buildings. Due to the constraints of early design, the adaptability potential indicator should be easy and practical to assess, enable the comparison of different design solutions and allow verifying an indicative performance level. After reviewing the literature and consulting designers, it was decided two evaluate the buildings adaptability through two sub-indicators: flexibility provision and adaptability capacity. The flexibility provision aims at evaluating transformation capacity of buildings by rewarding the design strategies that promote it. It consisted of a check-list, being thus a qualitative sub-indicator. On the other hand, the adaptability capacity aimed to quantify the available area to be modified, through a quantitative approach.

By introducing such concerns at the early design stages of a building design, sustainability awareness is raised, designers are supported with useful information and guidelines to set goals early in the design and pursue them throughout the process. Such a tool endows designers with sustainability concepts, improving their knowledge and confidence to contribute to a sustainable built environment.

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