Assessing buildings’ adaptability at early design stages

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Abstract. Buildings should be able to change and be adaptable according to newer requirements; otherwise, premature demolition can occur. The adaptability or lack of it in buildings affects the environment, society, and economy. If existing buildings are better-taken care of and re-used, their life expectancy extends, and fewer resources are used. Flexible and adaptable buildings enable not just recycling and reusing existing buildings, they allow upcycle of these buildings into urban regeneration projects. Additionally, buildings’ early design phases are critical for their sustainability. If adequate measures are taken at these stages, sustainability concerns are overcome in a much easier, faster, economical, and efficient way. This paper describes the importance of addressing sustainable criteria during early design, with special attention to adaptability criteria. Based on the concept of open building and aiming to promote ease of dismantling and adjustability, the evaluation proposed comprises two sub-indicators: flexibility provision and (ii) adaptability capacity. The first accounts for design strategies to accommodate change, through the transformation capacity. The second aims to quantify the availability of space to be changed and adapted according to the occupiers’ needs, following the open building concept by accounting the built area available to be transformed. By considering these aspects at the early design, it is possible to obtain buildings that live longer with lower environmental impact. Higher transformation ability means buildings can easier accommodate new requirements; greater disassembly potential can be achieved enabling replacement, reuse or recycling for the buildings’ materials and components, thus promoting buildings’ sustainability and resilience.

Keywords: Sustainability, early design, adaptability, flexibility, buildings

1. Introduction
Buildings should be seen from a long-term perspective, being able to adapt and accommodate new requirements. Still, conventional design and construction practices do not cope with this principle, often leading to premature demolition [1]. The European Commission aims at reducing 70% of the construction and demolition waste by 2020, through reuse, recycling, and valorisation [2]. The building’s adaptability or its absence has a major impact on the environment, society, and economy. If existing buildings are cherished and reused, their life expectancy extends, embodied energy is spared
and their life cycle environmental impact decreases [3]. Additionally, 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. Also, preserved buildings can work as a repository of cultural meanings [4]. Economically, there is a great industry fed by waste production; waste disposal or recycling must be paid, as well as demolishing, and deconstruction activities. If flexibility is foreseen during design, maintenance and refurbishment operations will have its time and cost reduced [5].

In this sense, a building should be planned to be reused, reconfigured according to future needs. It should embed change, adjust to new requirements, be adaptable and flexible. These abilities extend the buildings’ service life, bringing balance to the three-armed scale of sustainability [1]. Adaptability is a design characteristic which embodies spatial, structural, and service strategies, allowing the physical artefact a level of malleability to respond to users’ needs over time, enable improving the building’s lifespan [6]. Thus, buildings’ adaptability can be said as a cornerstone of sustainability. The assumption is that the building is more sustainable if its transformation capacity is higher (Figure 1). The transformation capacity of buildings can improve their flexibility, as it allows building to change, and adapt to new requirements. If a building can be rearranged to embrace change, modifying internal spaces for various uses, its flexibility increases [6].

In order to achieve more significant results in the buildings’ adaptability and flexibility, the building design should embrace these concepts and have its goals established early. It is at early design stages that, like any other requirements, adaptability ones, should be defined. When choosing design options, complexity and costs are directly involved and depending on them. If defined at early design, the costs can be lowered, and building’s performance improved [7].

In this sense, this paper aims to present a simple method to aid designers to establish flexibility and adaptability goals early in the project and allow them to compare and evaluate the performance of different design solutions regarding the defined goals. This evaluation method is part of a novel method to support early design decision-making towards sustainable buildings as presented in [8]. The adaptability indicator comprises two sub-indicators “flexibility provision” and “adaptability capacity”.

2. Adaptability in building design

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 [6, 9, 10].

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 [11].

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 [12, 13]. 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 [14]. Durmisevic [1] developed a
Method to assess the building’s transformation capacity based on its disassembly potential. Davico [15] presented an evaluation method to evaluate the level of a project’s flexibility.

The concept of Open Building was proposed in 1961 by John Habraken, where buildings were designed with separate systems to allow optimal layout freedom and modifications [16]. Habraken [17] suggested that to accommodate unknown future changes, different levels of decision making should be considered in the design process: tissue, support, and infill, and the urban fabric, containing base buildings with their fit-outs. Based on this layering concept a framework and terminology were created for building layers that could have different service lives, flexibility and performances and hence, that should be accounted when dealing with design for flexibility [12]: Site – Structure – Skin – Services – Space Plan – Stuff.

According to Davico [15], and Živković and Jovanović [18], the project aspects that most affect the buildings’ flexibility are building implementation, form, structure and size, circulation and technical systems positions, and usable areas size. The level of separation between buildings’ components and materials and their function also influences the level of buildings transformation capacity. Nevertheless, a building should not be too flexible, as it could also hamper its benefits [11].

Existing building sustainability assessment (BSA) methods consider adaptability to some extent, for mostly by (i) ease of disassembly and deconstruction, (ii) spatial structure (iii) indoor height clearance, (iv) accessibility of utilities cables and conduits and, (v) modularity, especially for office buildings [19]. Nevertheless, building sustainability standards recommend addressing adaptability in the sustainability assessment regardless of the building typology. ISO 21929-1:2011 defines buildings’ adaptability as the “ability to be changed or modified to make suitable for a particular purpose”, including aspects of flexibility and convertibility [20]. EN 16309:2014 says adaptability evaluation should engage “the provisions included in the building that allow it to be modified to make it suitable for a particular purpose, which may be a change of use or adaptation of its current use” [21]. Also, it states that building should stand with the accommodation of changing requirements from: (i) individual users, (ii) change of user, (iii) technical aspects and, (iv) change of use. The same standard presents measures that could be quantified to assess the building’s adaptability:

- 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).

Considering the aforementioned, adaptability it is a major aspect in attaining for sustainable buildings, and hence should be addressed in BSA tools, as recommended by the international standards. To enable its life cycle extendibility and to be in line with its users’ needs, a building should be able to adjust to changing needs.

3. Methodology
The work presented in this paper was carried out within the development of a decision-making support tool for the early design of residential buildings. The development of the tool based on a multi-dimensional approach. The general procedure accounted five stages: (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 decision to include adaptability in the sustainability decision support tool arose from stages (i) to (iii). Adaptability, spatial efficiency, ease of disassembly, reuse, recycling, and durability contribute to a building’s environmental impact [22] and are not legally covered. Besides, these can aid extend the building’s service life while promoting occupants’ life quality and comfort, if considered in the design. Corroborating the relevance of accounting for adaptability in sustainability assessments, the
questionnaire results, showed that designers do consider them pertinent [8]. In this sense, it was decided to include adaptability concerns in the under-development tool.

It was during stage (v) – framework proposal – that the adaptability indicator was established. Nevertheless, the process to develop it was a replication of stages (i) and (ii). Meaning that literature review and analysis of BSA tools were the basis for the elaboration of the indicator. The procedure focused on identifying existing research for promoting and assessing building’s functionality aspects and how this was already dealt with in BSA tools.

The premises for the indicators were that these should be easy to assess yet being accurate, allow alternative solutions comparison and reward the designers’ intentions and target goals. In later stages, if desired, designers could carry out a more complete and accurate analysis to validate the results achieved with the tool. In this sense, the indicators could be approached in two ways: i) descriptive and, ii) indicative. In the first, designers can describe or select the goals they are willing to attain and then verify the corresponding performance level. In the indicative path, designers establish the performance level to accomplish and get an indication of what they should implement to achieve such goal.

The two sub-indicators followed respectfully, an effort and quantitative approaches. The ‘flexibility provision’ evaluates the efforts a designer is willing to perform to attain a certain indicative performance level. Thus, it can be considered as a qualitative indicator. The ‘adaptability capacity’ is a quantitative indicator as it considers measures to perform the assessment.

4. Adaptability at early design

Valid design decisions regarding functional decomposition cannot be established during early design, as this stage only deal with the functionality of the assembly, and further analysis would be needed. Only when all necessary aspects have been considered, functional decomposition can be worked out [1]. Both Durmisevic [1] and Davico [15] proposed methods to assess a building’s flexibility and adaptability. While the first is too complex for a straightforward and quick analysis at early design stages, the second considers only a set of possible design solutions. At the same time, both procedures may not be directly in line with EN 16309:2014 recommended assessing measures.

Based on the concept of open building and aiming to promote ease of dismantling and adjustability, the two sub-indicators were developed within the adaptability indicator in the model for early design sustainability assessment: (i) Flexibility provision and (ii) Adaptability capacity.

4.1. Flexibility provision

The flexibility provision aims at evaluating the design strategies adopted to accommodate change, promoting future-proof homes and ease of disassembly. Its evaluation is obtained by calculating the transformation capacity (TC), according to a simplification of Durmisevic [1] method. Greater TC helps reducing the environmental impact of the building, as higher transformation ability enables simpler accommodation of new requirements, and greater disassembly potential allows replacement, reuse and recycling of materials and components.

The simplification was carried out to ease its use within a sustainability assessment at early design stages. It occurred at two levels: (i) fewer input levels were used, then the ones suggested by Durmisevic [1] and; (2) the aggregation process was simplified, only the dependency nodes were used and not the interdependency ones. In any case, if willing to attain a high TC, designers can carry out a complete analysis, in later stages of the project, where more data is available.

The evaluation procedure consisted of rewarding the designers’ efforts to promote a higher TC. To each effort checked, a grade is given, following Durmisevic [1] weights. The grades are then aggregated hierarchically according to the structure presented in Table 1. Designers should select which aspect their willing to implement to have the final TC value. Level 0 (input level) corresponds to the efforts to be selected, which aggregation results in the Level 1 performance by equation 1. From Level 1 to Level 4 (TC) the aggregation process uses the weighted sum method, using the weights given in Table 1.
\[ D_{sa_k} = \frac{\sum_{i=1}^{n} g_i}{n} \]  

where \( D_{sa_k} \) is the result of the Disassembly sub-aspect \( k \), \( g_i \) is grading from the independent variables \( i \) selected from Level 0 and \( n \) is the number of \( i \) selected.

**Table 1.** Aspects considered in the flexibility indicator and their corresponding weighting factors on the main aspects.

| Level 3 Transformation/Disassembly criteria | Level 2 Disassembly aspects to TC | Level 1 Disassembly sub-aspects | Level 0 Sub-aspects |
|--------------------------------------------|----------------------------------|-------------------------------|-------------------|
| Material levels [0.5] | Functional decomposition 0.67 | Functional separation 0.56 | Separation of functions 1.0 |
|                           |                                  |                               | 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 1.0 |
|                           |                                  |                               | Planned interpenetration of installations and load-bearing elements 0.8 |
|                           |                                  |                               | Unplanned interpenetration of installations and load-bearing element through a free zone 0.2 |
| Systematisation 0.33 | Structure and materials 0.5 | Clustering 0.5 | Clustering according to function 1.0 |
|                           |                                  |                               | Clustering according to material life cycle 0.6 |
|                           |                                  |                               | Clustering for fast assembly 0.3 |
| Interf interfaces [0.5] | Assembly 0.33 | Assembly direction based on assembly type 0.56 | Parallel – open assembly 1.0 |
|                           |                                  |                               | Stuck assembly 0.6 |
|                           |                                  |                               | Base element in stuck assembly 0.4 |
|                           | Assembly sequences regarding material levels 0.43 | Component/component 1.0 | |
|                           |                                  | Component/element 0.8 | |
|                           |                                  | Element/component 0.6 | |
|                           |                                  | Element/element 0.5 | |
|                           | Connections 0.67 | Type of connection 0.5 | Material/component 0.3 |
|                           |                                  | Accessory external connection 1.0 | |
|                           |                                  | Direct connection with additional fixing devices 0.8 | |
|                           |                                  | Direct integral connections with inserts 0.6 | |
|                           |                                  | Accessory internal connection 0.4 | |
|                           |                                  | Accessible 1.0 | |
|                           |                                  | 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 | |
|                           |                                  | Accessible 1.0 | |
The model used was simplified to be easy and practical to use within a whole sustainability assessment. A complete analysis is recommended in later design stages if one is willing to pursue high TC. The simplification was based in both, withdraw of the aspects that do not directly contribute to a more functional and easily convertible building, and give priority to those considered in existing post-design BSA tools [23, 24]. The DfD aspects left out of the assessment were: base elements, life cycle coordination, relational pattern, and geometry. For instance, the components’ lifecycle aspects were withdrawn as at early design stages, these are probably not available and geometry related aspects were also considered too detailed for early design. To ease understanding, some terminology was changed.

Considering this simplification, the weights of each level were converted to a percentage scale, according to their relevance for the final score and the weights from the withdrawn aspects were equitably distributed among those remaining in the same level.

The indicative performance levels follow Durmisevic [1] performance categories, in reverse order; category 3 corresponds to Level 1 and so forth (Table 2). Additionally, alternative solutions can be added and the results compared.

| 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 |

4.2. Adaptability capacity

The adaptability capacity quantifies the availability of space to be modified considering the occupiers’ needs, through the globally adaptable space, meaning the percentage of built area available to be transformed. Here, the adaptable area reflects the resulting area from the difference between the net internal area and the internal fixed area. This latter represents the area that is static and cannot be transformed. With this in mind, the Global Adaptable Space (GAS) is given equation 2 [15].

\[
GAS = \frac{NIA-IFA}{GEA}
\]

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 calculation follows one of two ways. In the first, if the adaptable area is known, GAS is obtained directly with equation 2, and the indicative performance level is given according to Table 3, which were obtained following the factor four rule [25]. In this sub-indicator it was decided to include four levels, to reward designs that even though do not achieve the 25% threshold had an effort to introduce some adaptability to the building.

| 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 second path, if designers do not have an estimation of the adaptable area, GAS can be estimated according to the attaining performance level, which uses the NIA calculated within space efficiency indicator [8]. When more accurate data is not available, IFA can be estimated as the area corresponding to kitchens and bathrooms, as it typically corresponds to those [15]. According to
Oliveira [26] in single family buildings, 9.64% of NIA corresponds to bathrooms, and 13.14% regards household activity spaces (kitchens, pantries, utility rooms, etc.). Thus, 77.22% of the NIA can be considered as the maximum area available to be transformed, when no other data is given.

Designers are thus asked for NIA and IFA or to select default calculation, with which the GSA is automatically calculated. Ideally, a building to be fully adaptable, its adaptable area should equal its net internal area.

If desired, in both paths, designers can add alternative solutions, to verify which is more sustainable and best fits the established building’s goal.

5. Conclusions

Literature shows that when considering sustainability concerns early in project design, the possibility to attain those goals is flawless. Thus, there is the need to implement tools to support decision-making in building projects to improve sustainability measures implementation.

Adaptability is not a hotspot of sustainability assessments. However, it plays an essential role in extending the building life cycle, thus reducing the buildings environmental impact. It also aids promoting people’s life quality and comfort, sense of belonging and it encourages presenting cultural heritage and local economy. There are few BSA tools considering adaptability, especially those targeting residential homes. Nevertheless, the ones doing so, are not appropriate at early design stages.

This work described insights of how could an early design support tool, be useful in promoting buildings adaptability. Two sub-indicators were presented– flexibility provision and adaptability capacity. The first evaluates the design strategies taken to promote easy adaptability to change through the transformation capacity of the solution. The second quantifies the area available to be modified.

Both indicators developed presented a simple and easy way for designers to compare design alternatives and base the decision-making on sustainability premises.

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Acknowledgments
This research work was supported by Fundação para a Ciência e Tecnologia (FCT) through POPH/FSE and QREN, funded by the European Social Fund, through an individual doctoral fellowship [SFRH/BD/76043/2011] and by EU Framework Programme for Research and Innovation – Horizon 2020 [grant agreement n. 642384].