ASSESSING THE GENERALITY AND ADAPTABILITY OF BUILDING LAYOUTS USING JUSTIFIED PLAN GRAPHS AND WEIGHTED GRAPHS: A PROOF OF CONCEPT

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Summary

This paper introduces an assessment method to quantify the generality and adaptability of building layouts in a fast and non-predictive way. The generality of building layouts is an indication of the amount of different uses a building can shelter. Adaptability is a measure of how easily a building can be changed to accommodate new uses.

Justified plan graphs analysis is an analytical graph-based method within Space Syntax theory that can be used to analyse the spatial configuration of building layouts. The generality of a layout can be expressed in terms its mean integration. The most innovative aspect of the assessment method is the use of weighted graphs to determine the adaptability of a building. Weighted links in the graph represent all possible connections that could be made between rooms by opening up existing walls.

The scope of this paper is to present a proof of concept of the basic idea of the assessment method, based on the analysis of both a social housing unit in a 1970's medium-rise building and an adaptable renovation of the same unit.

The paper ends by concluding that the concept of the assessment method is valid and by discussing points for future research.

Keywords: adaptability, generality, assessment, j-graph, weighted graph, space syntax

1 Introduction: expanding generality and adaptability assessment

Buildings are subjected to extensive and repeated renovation throughout their lifespan because they are adapted to suit changing standards, user demands and functional programmes. Designing, constructing and refurbishing buildings in a more adaptable way can make this process more efficient in terms of speed, cost and waste production [1]. Research on adaptable buildings always has one or several of the following goals: to allow more user control in buildings in order to increase quality of life (social focus); to reduce the production of constructional waste and increase reuse (ecological focus); or, to increase the affordability of buildings on a level of production and maintenance (economic focus)

[2]. Because it aims to improve on all three pillars of sustainability, adaptability could prove to be an important concept on the road towards sustainable buildings.

When it comes to evaluating this adaptability or capacity to change, existing methods mostly focus on either expert analysis of technological adaptability [3] or on scenario-based design assessment; this involves adapting a building design according to a set of pre-determined architectural programmes (the scenario) and analysing the results [1]. The latter method is slow and predictive, while the former are not necessarily suited to assess the adaptable capacity of existing, non-adaptable buildings [3].

This paper introduces a fast-paced assessment method to score the generality and adaptability of the spatial configuration of building plan layouts. A building is considered *general* when it can shelter a variety of functions or architectural programmes without having to change [4]. In this paper, the term *adaptable* building is used for a building that has been purposely designed to allow for change.

2 Determining generality and adaptability using plan graphs

The basic idea of the assessment method is that the generality and adaptability of an architectural layout are based on the spatial configuration of its rooms. The plan layout of a building is in essence an optimal organisation of the location of and connections between different functional spaces. This organisation is the spatial configuration.

The spatial configuration of a plan can be studied using a j-graph or Justified Plan Graph (JPG) [5], [6]. The JPG is one of the methods of Space Syntax, an important body of research on the use of graph theory to study and quantify characteristics and effects of spatial configurations in the built environment [6]. In a JPG, an architectural plan is reduced to a non-weighted graph, were nodes represent rooms (or more precisely, convex spaces) and edges represent connections between these rooms. The JPG allows the study of architectural space devoid of materialisation or function, shifting from a dimensional to a relational analysis of spatial configuration [7]. Consult Figure 2 for an example.

An important characteristic of a JPG is the value of integration, a dimensionless number that expresses how close a node is to all other nodes. It is in essence the inverse of the normalised and scaled total depth of a node (the distance from the node to all other nodes) [6]. Therefore, the mean integration value off all the nodes in the graph is a measure of the permeability of the graph. Integration values circle around 1, with lower values being less integrated.

The link between generality and integration has been made several times [8], [9], [4]. However, this link has hardly been studied. Manum [4] complements the JPG analysis of apartment units with surveys of their actual use, resulting in empirical support that more permeable lay-outs are used in more different ways and hence more general. Therefore, the mean integration of a spatial layout will be used as the *generality indicator* in the assessment.

The innovative aspect of the presented method is that it tries to evaluate the adaptability of a spatial layout by extending upon the JPG method used to assess generality. The generality of a particular set of spaces is based only on the *existing* connections between those spaces, not the amount of spaces. The adaptability could then be expressed as a form of generality that also considers *potential*, non-existing connections between the spaces.

These potential connections represent doorways that could be made between spaces by opening up existing walls. In essence, they can be used to determine to what extent an existing building can be turned into an open plan (or plan-libre) configuration. Of course these connections are theoretical in a non-adaptable building, as it is unlikely that every wall will be opened up. An example is shown in Figure 2.

In the plan graph analysis, potential connections get a weight that is higher than 1 (existing connections have a weight of 1). The potential weight is defined as the inverse of the probability of the connections – i.e. the difficulty of cutting through the existing wall – and is influenced by the characteristics of the wall (structural function, adaptability, embedded services, …). The integration value of a node is calculated using the shortest path to all other nodes, rather than the depth. The *adaptability indicator* is then defined as the mean integration of the weighted and extended graph of the spatial layout. Additionally, the *indicator of maximal adaptability* is the mean integration of the extended, non-weighted graph. It is an indication of the maximum adaptability that could be reached if all walls were to be adaptable (i.e. a probability of 1).

In essence, the indicator scores reflect the *amount* of architectural configurations that would fit the existing spaces of an existing architectural layout. Therefore, the assessment method does not verify any qualities of the existing or even future spatial configurations.

Theoretically, this graph-based generality and adaptability assessment could be used on any kind of building. Because the method has been developed to study adaptability on an urban level, it focusses on existing, ‘non-adaptable‘ buildings of any type. Nevertheless, it could also be applied to purposely designed adaptable buildings. However, in the next stage of this research the general applicability of the method will be verified by testing the method on different plan layouts.

The assessment tool based on the method has two components. The first component is a rule-set describing how to determine and draw the convex spaces used in the analysis. The second component is the software: 3D modelling software Rhinoceros is used to draw the convex spaces, the graphs and potential weights, and a Grasshopper script calculates the indicators, as well as other characteristic values of the graphs.

3 Proof of concept: assessment of conventional and adaptable cases

As a proof of concept of the assessment method, two plan layouts were analysed: the first is a housing unit of Building IX of the Model City housing estate in Brussels, a medium-rise housing block built in 1972 (see Figure 1 and 2); the second is a plan of that same unit after an adaptable renovation using the ‘re-design for change’ approach developed by Paduart [1] (see Figure 3).

For the proof of concept, preliminary values were defined for the probability of the potential connections: 0.3, 0.6 and 0.9 respectively represent walls that are difficult, average and easy to open up (resulting in weights of 3.33, 1.66 and 1.11). While most probabilities in the original unit are valued as 0.6, the renovation features walls that were designed for disassembly, resulting in most probabilities being 0.9. Walls with integrated plumbing decrease in probability (0.9 drops to 0.6 in case of the adaptable renovation, 0.6 drops to 0.3 in case of the original unit).

Fig. 1 *Building IX of the Model City housing estate in Brussels is a medium-rise housing block built in 1972. Pictures courtesy of Anne Paduart, used with permission.*

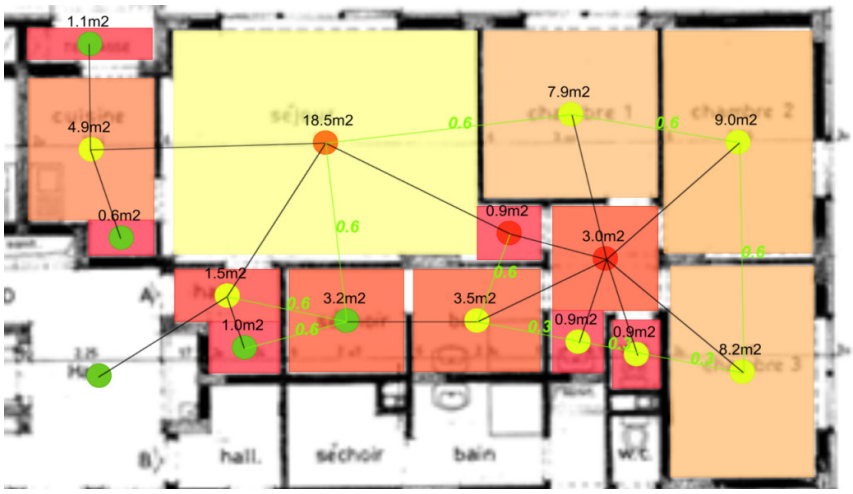

Fig. 2 *Graph analysis of an original housing unit in Building IX. Potential edges and their probability values are green, existing edges are black. Nodes are coloured by integration value (green to red). This image also shows that the assessment method can be applied using limited input – in this case, a scaled low quality picture of the original plan.*

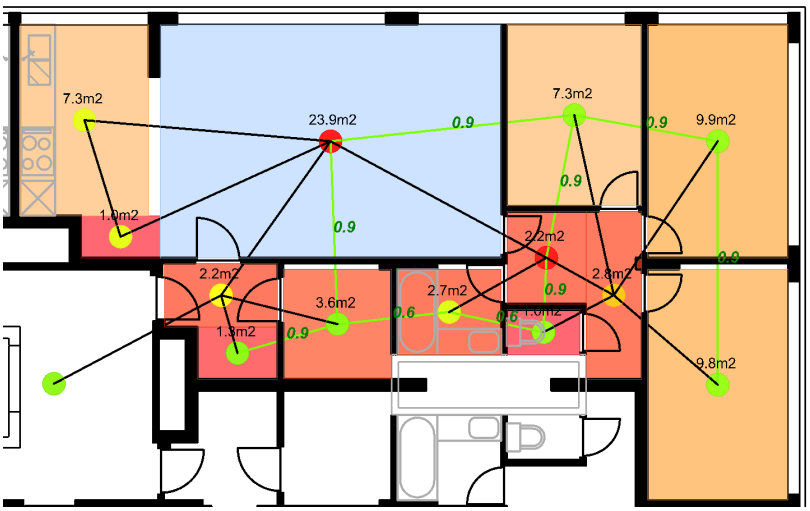

Fig. 3 *Graph analysis of the same Building IX housing unit after an adaptable renovation by Paduart [1], in which adaptable walls were introduced. The biggest changes to the plan layout are the more central washing room and the introduction of an open plan kitchen*

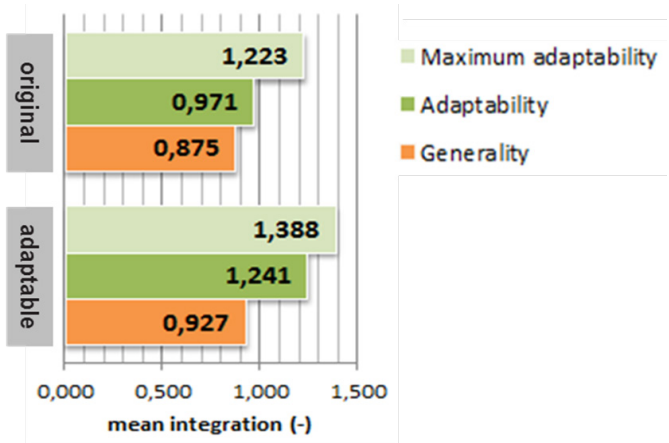

Fig. 4 *Indicator values for the original and the renovated housing unit show that the original unit is less general and less adaptable, proving the concept of the assessment method.*

The results for the indicators of generality and adaptability of both housing units have been listed in Figure 4.

The generality of the renovation is 6% higher than that of the original plan, largely because of the introduction of an open plan kitchen and the fact that its laundry room is now directly connected to the entrance hall (in the original unit, it is only accessible through the bathroom in the private area of the unit).

However, the biggest difference is the adaptability of both plans, which is 0.971 in the original versus 1.241 in the renovation, a 27.8% increase. This difference is only partially due to the higher probabilities of the adaptable walls – the maximal adaptability indicator, which is independent of the probabilities of wall connections, is 13.4 % higher for the adaptable renovation.

Finally, while the original unit's adaptability represents 27.6 % of the total adaptability that could be gained (i.e. max. adaptability minus generality), the renovation's adaptability accounts for 68.1 % of the highest achievable adaptability.

4 Conclusions and future research

The assessment method introduced in this paper has three main merits: it is fast compared to most existing methods, it requires minimal data input (an architectural plan) and it is applicable to existing buildings because it focuses on generality and adaptability. The most important addition of this paper is the proposal to view adaptability as an extension of generality by introducing potential connections. The proof of concept demonstrates that it is a useful way to compare the generality and adaptability of building layouts.

Because it is still under development, several aspects need to be further studied. A classification of the adaptability based on the integration values should make the results more understandable to the general public; this requires data from a broad range of cases. The probabilities of different wall types should be quantified, perhaps using multi-criteria analysis. Finally, in order to complement the dimensionless graph analysis, two indicators related to room surface area will be added during the next stage.

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