The Reviver Grammar: transforming the historic center of São Luís through social housing

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Abstract. This work explores the potential of Shape Grammars in generating solutions for the adaptive reuse of historic buildings. It proposes a transformation grammar for the Sobrado building, a typology present in the historic center of São Luís. The methodology proposes a framework for adapting buildings into multi-family apartments, considering spatial and structural requirements. The grammar aims to develop a formalism for repurposing historic buildings into social housing and considers the allocation of three types of apartments in the floor plan: studios, one-bedroom, and two-bedroom apartments. The adopted strategy for the distribution of internal spaces considers opening elements, such as windows and balconies, allowing to benefit from the natural daylighting characteristics of the buildings. This paper describes the grammar rules and its application to a case study building, aiming to demonstrate how the grammar supports different layout solutions for the same design space.

Keywords: Shape grammars, Adaptive reuse, Generative design, Mass customization, Sustainability

1 Introduction

The architectural composition of the historical center of São Luís maintains a rich ensemble of buildings representing the Luso-Brazilian architecture. With similarities to the *Pombalino* style from Portugal, it is an outstanding example of a dense, urban architecture adapted to the unique climatic conditions of equatorial South America. Efforts have arisen from both federal and state organizations to preserve and maintain the historic buildings, contributing to reviving the sense of community in the historic district. Adaptive reuse emerges as a viable solution for reintegrating buildings to new urban requirements, allowing to preserve historic buildings (Mısırlısoy & Günçe, 2016; Yung et al., 2014). However, adaptive reuse is a challenging problem that combines spatial, structural, and architectural requirements, along with current restrictions in design, enhanced in buildings with heritage value (Bullen, 2007; Shahi et al., 2020).

Since necessary modifications affect the layout configuration of the existing building, one can consider the adaptive reuse problems as a space planning problem. In this scenario, generative design techniques allow exploring different arrangements for a pre-defined problem, assisting professionals during complex design tasks (Agkathidis, 2015). Design is a highly complex task combining creativity, specialist knowledge, experience, and judgment concerning the objective and the aesthetic aspects of a problem domain (Mountstephens & Teo, 2020).

Incorporating the designer's knowledge into the GD process can lead to feasible solutions. In this context, Shape Grammars (SG) are widely applied to understand the formal and syntactic information underlying plan layouts for spatial configuration. SGs comprise a set of transformation rules that can be applied recursively to an initial form to generate new forms (March, 2011; Stiny, 1985a, 1985b). Studies have successfully developed SG to describe and analyze architectural styles or languages of designs by well-known architects (Benrós et al., 2012; Duarte, 2005; Ligler, 2021). However, few attempts have been made to produce reusable grammatical design systems for architectural design tasks, especially regarding the adaptation of buildings (Eloy & Duarte, 2015; Guerritore & Duarte, 2019).

This work utilizes shape grammar concepts to understand and produce a variety of arrangement of elements in the design space. Shape grammar formalism offers a visual, rule-based framework for interpreting architectural languages for over forty years (Ligler, 2021). Thus, this work develops a grammar-based methodology that supports the adaptive reuse process of historic buildings, focusing on the historic center of São Luís as a case study.

2 The architectural typology in the historic center of São Luís

This research explores the architectural typology of buildings in the historic center of São Luís (Figure 1a). This city maintains an important historical center, recognized as a UNESCO World Cultural Heritage Site since 1997. This ensemble preserves a significant architectural, historical and urban collection reminiscent of the XVIII and XIX centuries, a time of economic prosperity through the exportation of rice and cotton. The architectural ensemble shows strong traces of influence from the *Pombalino* buildings (Lopes et al., 2014). This constructive system marked Lisbon's reconstruction after the 1755 earthquake in the region known as *Baixa Pombalina*.

The design of *Pombalino* buildings included earthquake safety measures and sewerage channeling. Additionally, modular construction methods were implemented as the prevalence of prefabricated architectural elements, such as woodwork and carpentry (cage and roof structure), ironwork, lintels, and jambs in Lioz stone (Figueiredo, 2011). The construction of buildings in São

Luís considered a similar structural arrangement, also benefiting from modular construction. Due to the easy access to São Luís by the sea, most of the construction materials employed in the buildings came from Portugal by ships.

Structurally, *Pombalino's* buildings presented a three-dimensional locking system, also known as *gaiola pombalina,* formed externally by the main walls in stone masonry and internally by the frontal walls. Frontal walls were constituted by a skeleton of wood, formed by vertical, horizontal, and diagonal pieces, known as Santo André cross (Figueiredo et al., 2011). Using this system, it was possible to build lighter and more flexible elements in the event of an earthquake, unlike traditional stone or brick masonry walls (Mascarenhas, 2005). Although there was no risk of earthquake in São Luís, this construction system is found in many buildings in the region (Figure 1b).

a) b)

Figure 1. The historic center of São Luís: a) Sobrado buildings; b) wall evidencing the Santo André cross structure. Source: a) Source: The Authors, 2022; b) Figueiredo et al., 2011**.**

The main difference between *Pombalino* buildings and the constructive system found in São Luís is found in the distribution of volumes within urban blocks. *Pombalino* buildings followed a strict distribution per block, resulting in a uniform volume, usually a five-story distribution. However, the buildings in São Luís present a variation in the number of floors in the same block distribution (Figure 2). Thus, considering the volume and composition of the façade elements, the buildings in the historic center of São Luís are classified as *Solares*, *Sobrados*, and *Casas Térreas*. The majority of buildings are classified as *Sobrados*, especially in the federal area of protection (Figueiredo, 2014). The term *Sobrado* primitively designates the space left or gained due to the suspended floor enabled by the topography level differences (Ghignatti, 2020).

Figure 2. Schema representing the architectural set of São Luís, featuring blocks of buildings at varying heights. Source: Figueiredo et al. (2011).

São Luís attracts attention for the number of buildings with Portuguese tiles in their facades (Figure 3a). Besides decorative purposes, these tiles provided impermeability during the heavy raining season as well as thermal isolation during summer seasons. In addition, those buildings usually presented internal patios with glazed closure (wood, glass and shutters) of the back balconies, allowing ventilation and light into the buildings (Figure 3b).

a) b)

Figure 3. Façade elements characteristic of Luso-Brazilian typology: a) Portuguese tiles, b) Internal patios. Source: a) Source: The Authors, 2022; b) Figueiredo et al. (2011).

3 Methodology

This work explores the potential of shape grammars in generating floor plan layout solutions for the adaptive reuse of historic buildings in the historic center of São Luís. The proposed grammar is entitled *Reviver*, a word from Portuguese meaning 'to revive'. The name is based on a rehabilitation program created in the late 80s to preserve the city's heritage identity and nowadays, locals refer to the historic center using this term. The methodology proposes a framework for adapting buildings into multi-family apartments, considering spatial and structural elements.

The grammar aims to develop a formalism for repurposing historic buildings into social housing and considers the allocation of three types of apartments in the floor plan: studios, one-bedroom (1B1B), and two-bedroom apartments (2B1B). the design space for producing apartments configurations is the original built-up area (within exterior walls).

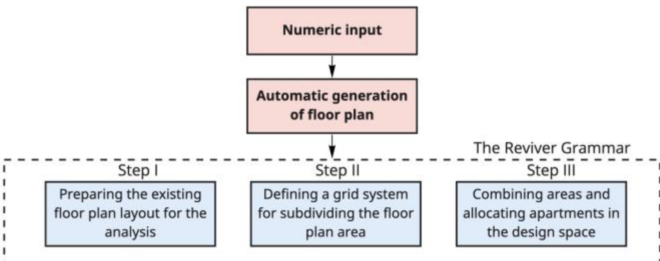

Figure 4. The Reviver Grammar methodology. Source: The Authors, 2022.

Figure 4 summarizes the grammar-based methodology. The grammar considers a numeric input to automatically generate the original floor plan layout. The first step refers to adjustments that may be necessary to perform to the floor plan obtained considering the numeric data input. These adjustments refer to preparing the floor plan for the transformation analysis, such as visually differentiating element types, identifying the landing area for the stair, and identifying the primary and secondary facades. The second focus on defining a grid system for subdividing the floor plan design space. Lastly, third step defines layout solutions for multi-family apartments considering the design space. The implementation of this process is conducted using Python and rhino script syntax, which facilitates the implementation of visual components of this research. However, this paper will not focus on defining the computational implementation, but mainly the grammar strategy.

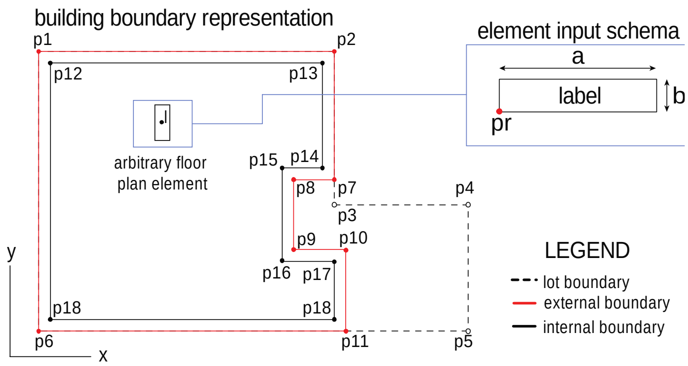

Figure 5. Abstract schema for defining the data input for the floor plan configuration. Source: The Authors, 2022.

The numeric input is designed to be obtained using documentation techniques, such as laser scanning and photogrammetry, and aims to provide an automated strategy for defining the original floor plan layout. Essentially, any floor plan configuration is abstracted as two data sets (Figure 5): a) a list of points defining appropriate boundaries of the building; b) geometric information of existing elements, such as walls, windows, stairs, patios, etc.

Three boundaries are defined as relevant for the adaptive reuse process: the urban lot boundary (*lot*) and the external (*ext*) and internal (*int*) boundaries for the built-up region (inside external walls). The data input for representing these curves are the coordinates (x, y) of the points defining each boundary.

Secondly, information on each element on the floor plan must be provided. Floor plan elements are abstracted as a rectangle, as detailed as the arbitrary internal element in Figure 5. To determine the element configuration, each element is abstracted as the following input variables: reference point defined by coordinates in x and y direction (p_r), dimension of element in x-direction (a), dimension of element in y-direction (b), label for each element $(label)$. The labels list will depend on the architectural typology. For the Luso-Brazilian architecture, the list of elements is: external masonry wall (*ew*), gable wall (*gw*), stone column (*cl*), internal masonry wall (*iw*), frontal wall (*fw*), partition wall (*pw*), entrance door (*en*), balcony (*bc*), secondary windows (*wd*), stairs (*st*) and patios (*pt*).

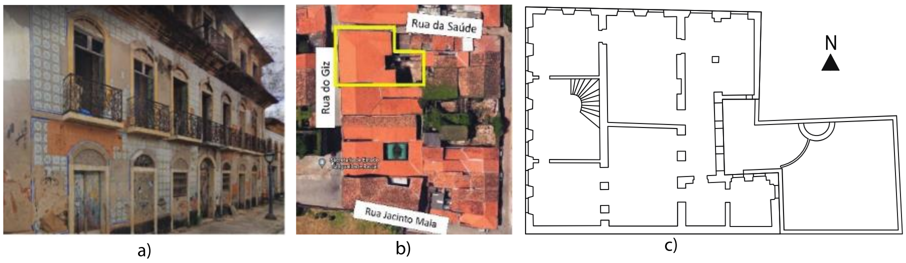

Figure 6. Case study building: a) facade, b) aerial view, c) floor plan configuration. Source: The Authors, 2022.

A case study building is selected to illustrate this research methodology. The building is located at Rua do Giz, 445, São Luís (Figure 6). This *Sobrado* is part of an existing rehabilitation program, coordinated by the city of São Luís, to adapt the structure for mixed-use building, with public offices on the ground floor and multi-family apartments on the first and second floors. Most *Sobrado* buildings were single-family houses originially. However, nowadays most buildings are vacant, which is the current state of the case study building. Figure 7 illustrates the existing floor plan configuration generated considering the input data for the case study building. The total built-up area (within internal boundary) is equal to $481\ m^2$.

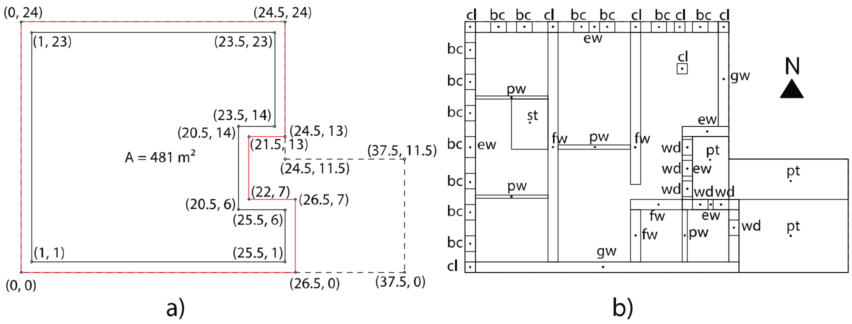

Figure 7. Schema representing the floor plan configuration generated based on the two datasets: a) building's boundaries, b) existing floor plan elements. Source: The Authors, 2022.

4 The Reviver Grammar

The Reviver grammar is composed of 10 stages, as illustrated in Figures 8. Stage 1 focuses on coloring the relevant elements for the analysis, aiming to define visually distinct shapes (Knight, 1989). For elements where the thickness is important to distinct, like walls and their contained elements (windows, doors, etc), l and t represent the length and thickness, respectively. For other elements (columns, patios, stairs, etc.), dimension representation follows the variables specified in the abstracted schema (Figure 5), where the dimensions

are represented by a (dimension in x direction) and b (dimension in y direction).

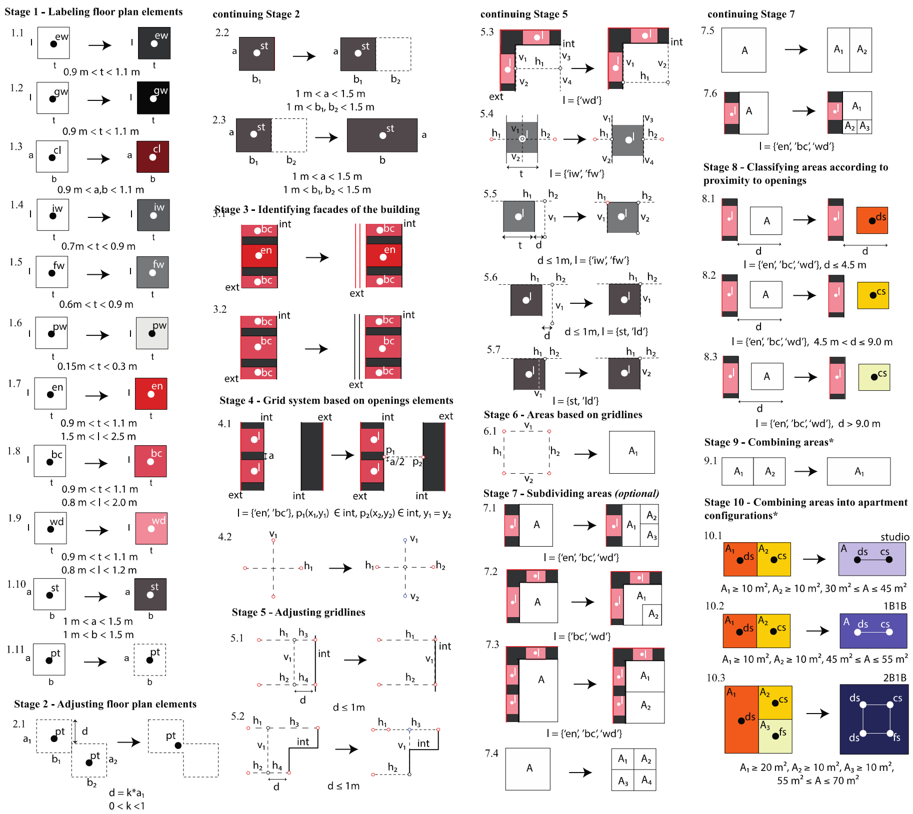

Figure 8. The Reviver Grammar. Source: The Authors, 2022.

Since the data input abstracts elements as rectangles, it may be necessary to perform adjustments on the spatial configurations. Stage 2 focuses on defining adjustments to the existing data input configuration. Since patios may be composed of multiple curves, due their irregularity, they can be grouped as one area (rule 2.1). In addition, it is necessary to define the landing area space for stairs (rules 2.2 and 2.3). For orientation purposes, it is also necessary to encode rules to identify the main facade (rule 3.1) and secondary facades (rule 3.2). This ruleset is used to differentiate if a building is a corner building (both rules are applied) or is a middle building (only rule 3.1 would be applied).

Then, a grid system is defined aiming to facilitate the transformation process for converting the existing space into multi-family apartments. This study focuses on locating the existing opening elements and generating grid lines based on their location. This process is converted into rules during stage 4. In the ruleset, opening elements (main entrance and façade windows/balconies) are used as a reference for defining the grid line.

The grid line is defined considering distance between two façade elements (a). It starts from a point located in the middle distance between two façade elements, and it is extended until a point located in the parallel internal boundary curve (rule 4.1). In sequence, each grid line is subdivided into smaller components considering the points where vertical and horizontal lines connects each other (rule 4.2).

When applying the grid division as defined in stage 4, some undesirable patterns may arise due to the configuration of the existing building, such as grid lines coalescing secondary windows or within a small distance from division elements (such as external walls). Stage 5 presents rules to modify the grid configuration to avoid these patterns. A critical characteristic while preparing the floor plan is adjusting the grid to prevent grid lines from intersecting structural elements. Thus, the design space considers structural elements such as masonry and frontal walls as part of a fixed domain (rules 5.4 and 5.5).

In contrast, since partition walls do not have a structural function, they are not included as a restricted domain when defining grid lines. Other adjustments performed to grid lines are to the ones close to the internal boundary (rules 5.1 and 5.2), intersecting windows (rule 5.3), and crossing or close to stair elements (5.6 and 5.7).

The grid specifies areas for transforming the existing building layout for a multi-family apartment floor plan. Stage 6 presents the rule for generating areas based on the grid lines. Then, the resulting areas can be subdivided to refine the grid size, increasing the combinatory possibilities, following patterns described in stage 7. This stage is optional to allow for design flexibility in the use of the grammar. It is optional since the grammar can produce variations considering the areas defined based on the grid system (as defined in stage 6). Then, each area is labeled according to its proximity to openings (stage 8). These areas are classified as: a) areas exposed to direct sunlight ('ds') b) areas without openings but still relatively close to spaces with openings ('cs'), and c) areas far from sunlight ('fs').

For simplicity, areas are illustrated in stages 9 and 10 as squares. However, they can have different configurations as long they respect the prescribed limits in squared meters. In stage 9, areas with the same classification are combined according to limits defined based on the type of apartment (studio, 1B1B and 2B1B), further described in stage 10. Studio apartments must have a total area between $30\ m^2$ and $45\ m^2$, 1B1B must have a total area between $45\ m^2$ and $55\ m^2$, and 2B1B must have a total area between $55\ m^2$and $70\ m^2$.

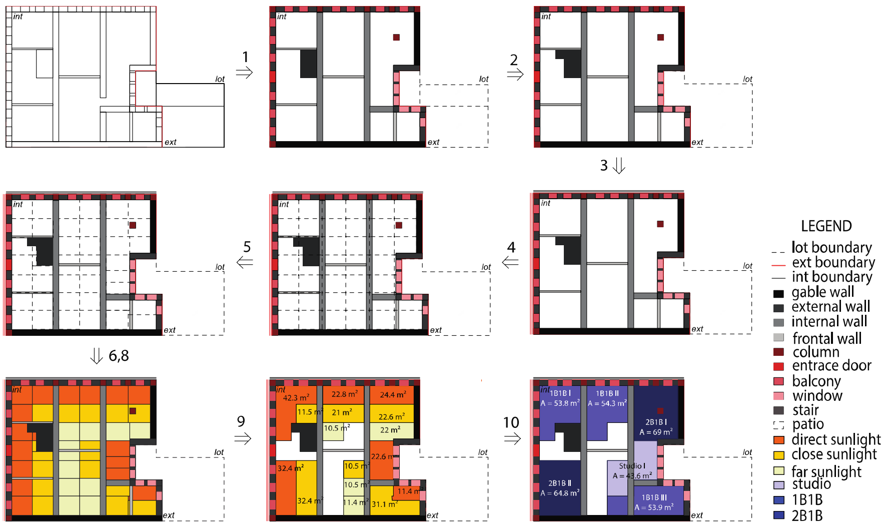

Figure 9. Derivation process using the Reviver Grammar for the case study building. Source: The Authors, 2022.

In stage 10, different area types ('ds', 'cs', 'fs') are combined apartment configurations. Figure 9 illustrates the derivation process for the case study building, showing one possibility of floor plan for multi-family apartments. This derivation did not consider stage 7 (the subdivision of spaces ruleset).

5 Multi-family Apartments Configurations using the Reviver Grammar

Six different floor plan layouts are produced to verify the proposed grammar's applicability in achieving various design solutions. Two different strategies are defined: a) space layout based on the original grid system, which does not apply rules in stage 7 (Figure 10); b) subdividing spaces by applying rules in stage 7 (Figure 11). Rules 7.4 and 7.5 can be recursively applied to refine the subdivision layout. Each variation consists of different layout configurations, with apartment types varying between studios, 1B1B and 2B1B.

The first variation includes one studio, three 1B1B, and two 2B1B; the second contains three studios, three 1B1B and one 2B1B; the third has five studios and three 1B1B. The total area for multi-family apartments compositions is equal to $339.4\ m^2$ for variation one and $342\ m^2$ for variations two and three. In contrast, using strategy 2 the total area of apartments could be increased, since a more refined grid is applied. The first variation has one 1B1B and five 2B1B; the second has two studios, two 1B1B and three 2B1B; the third has three studios, four 1B1B and one 2B1BThe total area for multi-family apartments compositions is equal to $378.1\ m^2$ for variation one and $381.2\ m^2$ for variations two and three. Table 1 presents the percentage of apartments areas for each solution in comparison to the total floor plan area ($481\ m^2$).

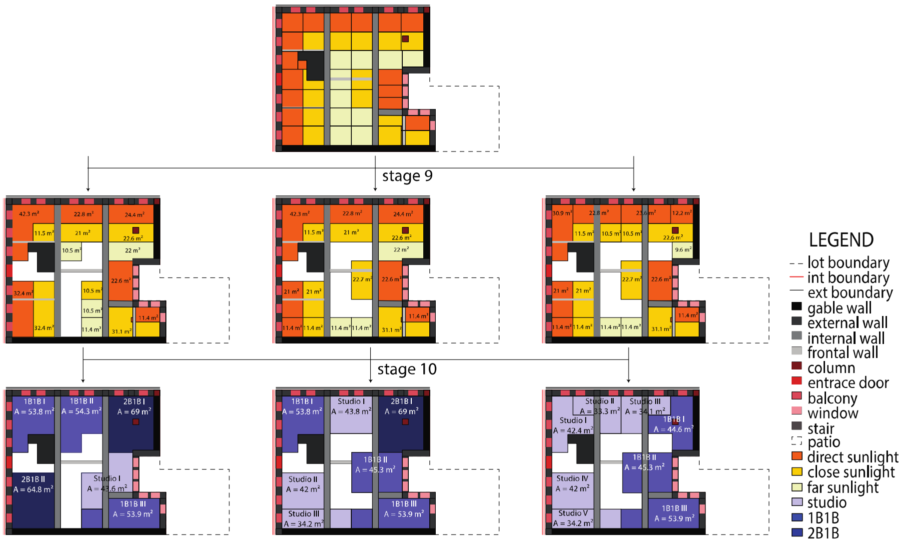

Figure 10. Three different configurations for the case study building produced using strategy 1 (stage 7 is not applied). Source: The Authors, 2022.

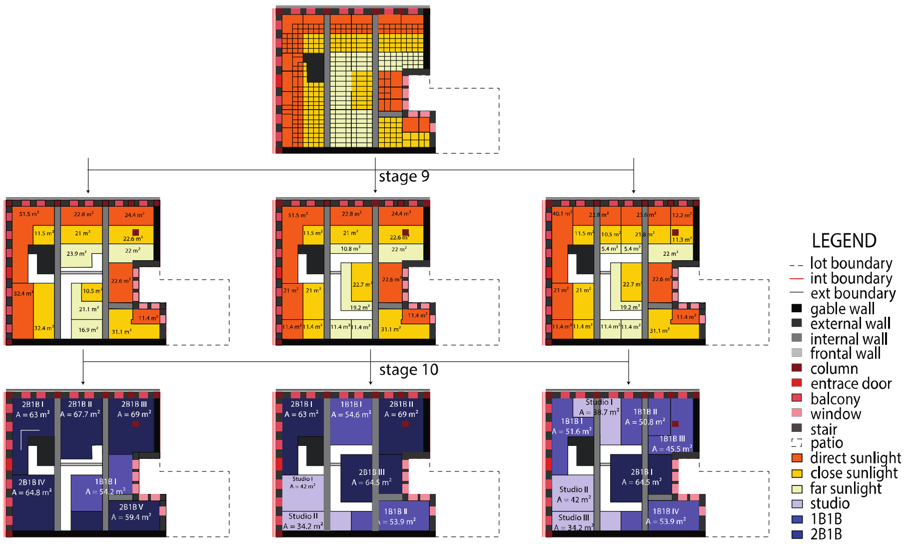

Figure 11. Three different configurations for the case study building produced using strategy 2 (stage 7 is applied). Source: The Authors, 2022.

The transformation grammar can be applied to any floor in the building; however, variations produced in Figures 9, 10 and 11 illustrate possible configurations for the upper floors of the building – since these floors should be adapted into multi-family apartments according to the existing rehabilitation project. The white internal spaces in these variations represent potential corridors connecting apartments. The best designs should maximize the total area of apartments and minimize the corridor areas.

Table 1. Apartments/floor plan area ratio for solutions using strategy 1 and 2.

Strategy	Variation 1	Variation 2	Variation 3
1	70.56%	71.10%	71.10%
2	78.61%	79.25%	79.25%

6 Conclusions

Adaptive reuse is a challenging task that involves understanding a building's configuration, repurposing it for a new use. Thus, this research investigates how shape grammar formalism can automate the space allocation process for adaptive reuse projects, focusing on historic buildings. The grammar, entitled *Reviver*, presents ten stages that assist transforming an existing floor plan configuration into multi-family apartments. It effectively produces variations of designs considering three different apartment types: studios, 1B1B and 2B1B. This project is part of a broader scope of mixed methods to study how generative design can support adaptive reuse in terms of spatial and structural problems. Future work will integrate the grammar with genetic algorithms and GANs to support the combination of human and machine expertise for the adaptive reuse process.

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