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Architecture for Community-Based Ageing—A Shape Grammar for Transforming Typical Single-Family Houses into Older People's Cohousing in Slovenia

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Abstract: In Slovenia, the existing organised housing infrastructure for people over 65 years of age is insufficient and lacks diversification. Older people are often homeowners, many of whom dwell in large, underused single-family houses that require adaptations. Some have the potential to be transformed into small co-housing communities of 3–6 older people. The houses in question are mostly pattern-book houses of various types, built in the first decades after WWII. To approach the problem of converting this mass resource while providing enough flexibility for individual customisation, a shape grammar was proposed, with the intension of expanding the range of design variations for the transformation of single-family houses and presenting them to both users and architects for further assessment. The shape grammar was inferred based on a corpus of case studies developed by architecture students across two weeklong workshops. Three general strategies emerged—splitting the house vertically (according to sleeping/private and living/communal functions), horizontally, or with the maximum number of sleeping/private spaces. Essential spaces were catalogued to determine the conditions and requirements for assigning every transformation rule. The result was a simple, yet versatile composition generator. Through the development of a user-friendly interface, this resource could be used to empower potential inhabitants in the transformation design process.

Keywords: older people; housing; single-family house; shape grammar; reuse; adaptation; ageing in place; co-design; mass customisation

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1. Introduction

1.1. Motivation and Background of the Study

The ratio of older people all over Europe is rising rapidly [1]. In Slovenia, retirement homes are unable to keep up with the demand for vacant rooms [2] and are often seen as a less desirable last resort for those who cannot dwell on their own anymore [3]. They can only house 3–5% of people over the age of 65 and are unequally distributed across the country, making access to them limited in some areas [4]. Retirement homes are also seen as overly institutional, whereas sheltered housing is often expensive and exposes the inhabitants to age-based segregation [3].

According to a survey on the housing preferences of older people in Slovenia, only 1.6% of the participants expressed the wish to move into a retirement home, whereas 44.4% would like to stay in their current home and the remaining 54% were interested in exploring other housing options [5]. This is compatible with observations made across the European Union. According to the WHO's Regional Office in Europe, older people mostly wish to stay in their own homes and in familiar surroundings for as long as possible, rather than moving to potentially more adapted or accommodating locations or residential care facilities. The validity of "ageing in place" as a favourable strategy to address older people's housing needs has been widely adopted. Studies suggest that the ratio of maladjusted and unhealthy housing for older people in the European Region is high. Existing housing stock may therefore need modification [6]. In addition, the Architects' Council of Europe [7] states that rather than demolition, building conservation and retrofitting should always be envisaged as a preferred option. Furthermore, the Council encourages participatory design in housing, where citizens are empowered to participate in the creation and regeneration of the urban fabric through residents' cooperatives and collective self-development [7]. Housing is crucial for older people as they can spend about 70–90% of their time at home [6]. This indicates that organising an in-house community of coinhabits may be a good approach in order to battle older peoples' increased tendency to experience loneliness and isolation. Community-based ageing also recognises the importance of sharing close neighbourhood ties with people who are not necessarily from one's own family. Additionally, the participative management of the house and communal facilities gives older people the opportunity to make decisions together and remain socially integrated [6].

According to representatives of Slovenian older people's organisations [8], as well as various state strategic documents [9–11], there is a need for developing non-institutional, community-based older people's housing for people to be able to age-in-place, or at least within their known, chosen community. However, despite the consensus between older people's representatives and state bodies, there is a lack of action plans and active research to implement non-institutional older people's housing typologies in Slovenia.

1.2. The Current State of Older People's Housing Conditions in Slovenia

Organised housing for older people in Slovenia has been linked to institutions ever since the 14th century [3] and today consists almost exclusively of retirement homes—that is, institutional housing—and a limited number of mostly commercially driven sheltered housing residences. In Slovenia, retirement homes are a combination of both nursing homes and residential home facilities—the two types are not differentiated [12]. Alternatives are scarce. The authors of the aforementioned survey on the housing preferences of older people in Slovenia, Kavšek and Bogataj [5], noted that the participants they interviewed were mostly not familiar with the concept of, for example, a retirement village (or other community-based housing for older people). The reason for this is likely the fact that this kind of housing does not currently exist in Slovenia. Therefore, the authors concluded that a large number of Slovenian older people are interested in some type of change in their dwelling style; however, the existing housing fund does not currently offer enough possibilities [5].

Due to the scarcity of attractive alternatives, most older people in Slovenia continue to stay in their regular dwellings for as long as they can. Older people are also mostly homeowners—about 90% live in dwellings that are owned by themselves or other members of the household [13]. This places older people in Slovenia far above the European average—in 2018, some 60.9% of older people living alone in the EU-27 were homeowners, and a 2019 survey showed that more than half of older people in the EU (50.6%) lived in under-occupied dwellings, i.e., dwellings that were too large for their needs [14].

Similarly, many of Slovenia's older people live in now under-occupied single-family houses built within the first decades after the Second World War [15]. These houses are often quite large, built with the option of housing two generations in mind. The owners—mainly self-builders—frequently chose to build them in a way that would allow one of the floors to become a separate apartment for their future grown-up children. Due to societal and economic changes, this did not always happen, and older people are often left dwelling in large houses that are expensive to heat and have too many upkeep demands.

The houses that many older people inhabit at the moment still represent a useful resource for re-use. New construction usually represents only around 1% of the total housing stock and many experts and institutions recommend the modernisation and adaptation of existing homes and buildings instead [14]. In the study presented below we attempted to develop a new typology combining the widespread interest in ageing in one's own community and the utilization of the existing infrastructure of under-occupied typical single-family houses.

1.3. Manuscript Content and Outline

To deal with this wide-ranging problem, we needed to develop a formal design process that was flexible enough to be applied widely to different house types and contexts. The houses can henceforth be adapted in a way that changes their composition from family dwellings into co-housing communities for 3–6 older people, which include both private and communal spaces. The reasons for proposing a system, rather than a how-to guide for architects, include the following. Firstly, these houses are numerous and it would be difficult to achieve a mass refurbishment project by focusing on each house individually. Secondly, architects in Slovenia usually have little to no experience with cohousing in general, and even less with cohousing for older people. Furthermore, the house owners, older people, operate with limited funds and often cannot afford to hire an architect. Instead, we have proposed a design process, conceptualised by architects, that can be used by a large number of house owners. As a result, the future coinhabitants can begin their cohousing process by codesigning their future dwelling, helping to empower them and support a greater sense of ownership and involvement.

The study presented here was therefore an attempt to systematise architectural knowledge in a way that makes it transferable and capable of generating a wide range of compositions. To achieve these goals, a transformation shape grammar was developed to help generate various possible architectural solutions.

This article opens with an introduction, followed by a description of typical Slovenian single-family houses, which are covered in the first quarter of Section 2, continuing with a theoretical overview of formal methods in architecture and the basics of shape grammars. The third subsection explains the research design utilised in this study, and in the last subsection of the Methods and Materials, we present a corpus of 15 designs and the subsequent analysis that we carried out to infer the shape grammar.

Section 3 contains three sub-sections: Rules, Strategies, and Demonstration. The first introduces the more than 120 recorded transformation rules, classifying them by category. It also includes an explanation of the requirements built into specific space function rules. We observed predictable combinations of spaces forming in regard to bedroom suites, so sets of rules were added to speed up the generation process. The second subsection presents the three different strategies recognised as the determinants of the transformation sequences, which are also expanded on floor by floor. The Demonstration subsection provides a graphic depiction of how applying the transformation rules according to the chosen strategy enabled us to generate a fully functioning set of plans for transforming a single-family house into a dwelling for the cohabitation of a small group of older people.

In Section 4, we explain how the analysis process indicated that preparatory rules could also be used before the transformation process to remove irrelevant or distracting factors within the initial shape of the floor plan. We also comment on the identified limitations of the study.

In Section 5, we state that the shape grammar was shown to function and produce a wide range of floor plan variations; however, a user-friendly interface will be needed in order to make it useful and intuitive for the user group that it seeks to empower in the design process—older people.

2. Methods and Materials

2.1. Observatory Framework—Defining the Typical Post-War Single-Family House

According to Brezar, [16] the average Slovenian single-family house usually has 120–200 m^2 of living area, not including the basement, and is set in the middle of a relatively large plot, usually spanning somewhere from 400–1000 m^2. The shape is generally similar to a square, with outside measurements normally ranging between 8 m $\times$ 8 m and 12 m $\times$ 12 m. It usually includes three levels—a basement, a ground floor, and a first floor—and often contains an attic (which is non-habitable). The ground floor is often elevated a meter or so to allow the half-sunk basement to have windows. Typically, it is covered by a simple double-pitched roof construction. Most of the characteristics observed by Brezar [16] were confirmed through our own analysis of the house examples, apart from the fact that our research (looking at existing houses) also identified several houses without a half-sunk basement that only had two storeys, with the ground floor based at ground level.

The first stage of research into single-family house types began by consulting one of the most extensive pattern book house catalogues from the former Yugoslavia, entitled Katalog tipskih projekata sa preko 1300 tipova (eng. A Catalogue of Type Projects containing over 1300 types) [17]. This needed to be narrowed down due to the fact that the former Yugoslavia included many diverse areas that are not located in modern-day Slovenia and are therefore less relevant to our research. The catalogue also contained examples of temporary living units, such as holiday houses, as well as garages and small-business commercial buildings that were not seen as relevant. It represents a valuable resource; however, to ensure that our research was focused on Slovenia, we decided to obtain floor plans of houses that had been built in various locations around the country.

As explained further in Section 2.3, 4 sample house plans from different regions in Slovenia were obtained to facilitate the first student workshop, conducted in May 2021 (see one of the examples in Figure 1). Using existing, built examples also allowed us to study how the houses were usually placed in the surrounding terrain. For the second student workshop, held in May 2022, 18 more existing house examples were obtained, this time with the help of Design Studio Sadar at the Faculty of Architecture, and 4 were chosen to be used by the students attending the workshop. The criteria for choosing the houses were designed to ensure that we worked on the most typical (i.e., most repetitive) layout concepts seen in these houses and found solutions for each one of them in order to construct a useful transformation shape grammar that would be applicable to a large number of houses. The number also had to be contained due to the workshops only lasting one week and the number of participants being limited to 8 and 10 people.

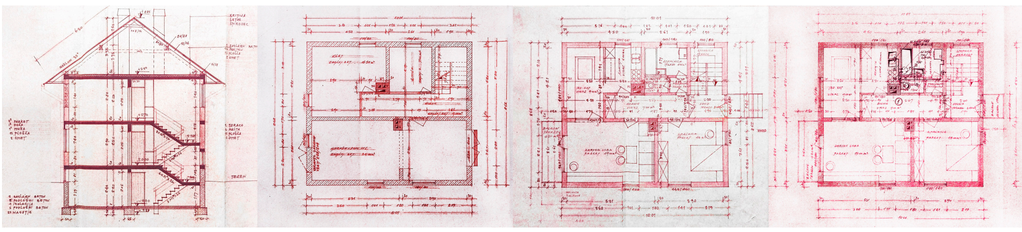


Figure 1. An example of a house located in Hrastje, Kranj, showing sections and floor plans—drawings collected on-site, donated by the owner. Obtained by Ana Belčič in 2021.

When looking at examples gathered for the workshops, as well as those in the pattern book catalogues, some common characteristics become evident. The houses had a somewhat predictable structure, with two or three main spaces splitting off from the communication axis of the hall on each side of the floor plan. The interior space dimensions were designed in a way that insured that the loadbearing distance between walls was never more than 4 m or 5 m at most (Figure 2). This ensured a simple build that was within the skill level of self-builders working with brick and concrete slab construction. The staircases were normally straight or U-shaped, or rarely L-shaped, and were mostly simple (Figure 2), which makes sense when considering that a lot of self-builders performed as much construction work as possible on their own, and they were not formally trained. Although many of the houses had a half-sunk basement and three levels (therefore, a basement, an elevated ground floor, and a first floor), there was also a significant amount of cases where the ground floor was situated at ground level—in this case, the house usually lacked a basement and consisted of only two levels. This led to two different design approaches, as explained below. The construction type used in most of these houses was mostly a combination of clay bricks or concrete building blocks interrupted by reinforced concrete floor slabs.

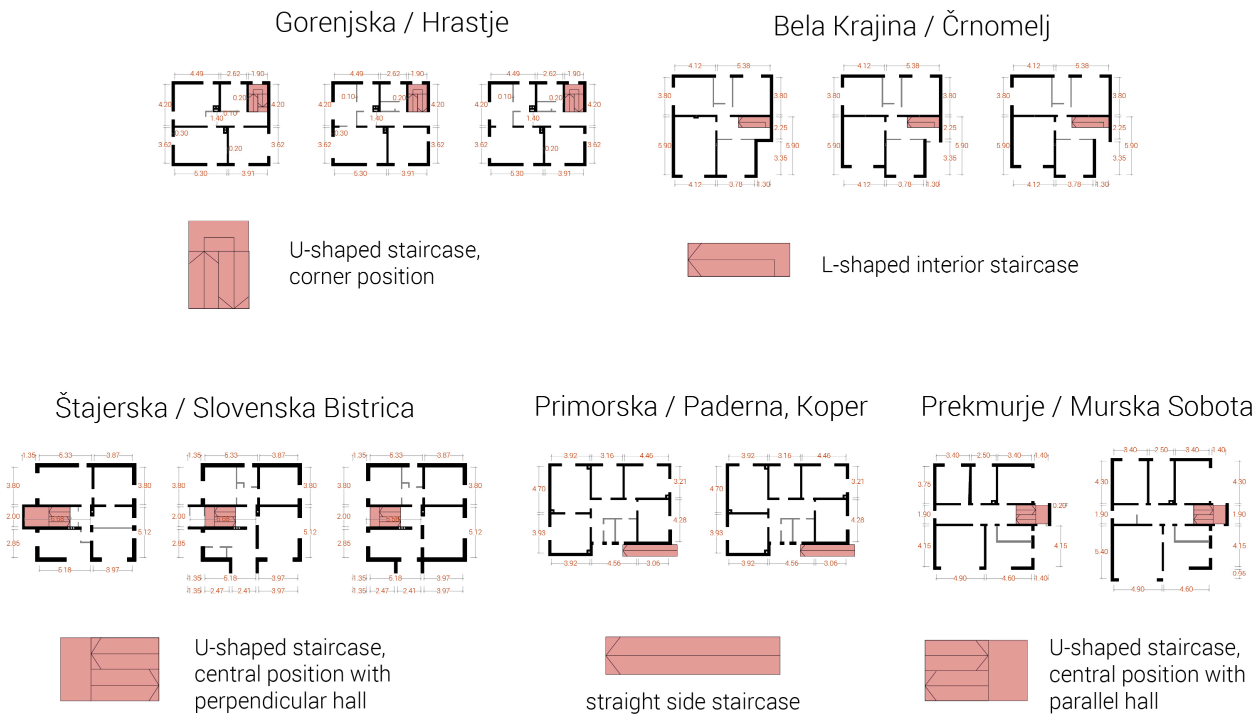


Figure 2. Existing floor plan analysis of five houses in different locations (Gorenjska/Hrastje; Bela Krajina/Črnomelj; Štajerska/Slovenska Bistrica; Primorska/Paderna, Loper; Prekmurje/Murska Sobota) (Ana Belčič, 2022).

When looking at the way the single-family houses in question were built, it also became clear that they were intrinsically personal projects, in many cases taken on in a do-it-yourself (DIY) fashion, where the owners were highly involved in the building work, as attested by the archival images shown in Figure 3 [18]. As a result, each house was somewhat customised to the needs of the inhabitant, while retaining the overall compositional characteristics of single-family houses from the afterwar period.

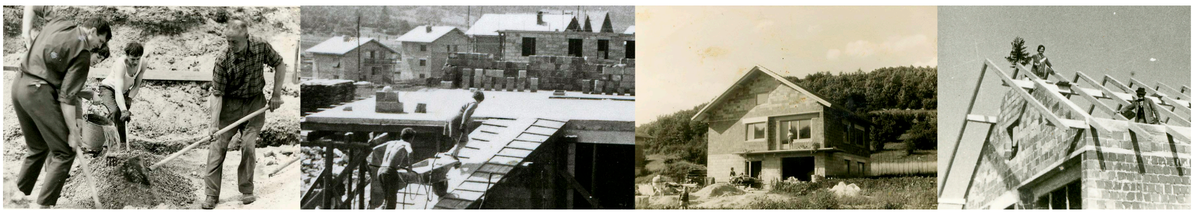


Figure 3. Archival images of the DIY building process. Source: http://stareslike.cerknica.org, accessed on 1 February 2023, provided by provided by Franc Perko; left and centre-left [18] and Alojz Janeš; centre-right and right [19].

2.2. Transformation Shape Grammars

Single-family houses are a mass resource, which is why tackling the question of their transformation into cohousing communities for older people requires a systematic yet flexible approach. This led us to search for a method that could produce simple compositional variations and make it easier for users to become involved in the planning and decision-making process. Mass customisation is "a systematically supported creative way of planning" [20] (p. 20) that "combines the principles of mass, homogenised building with a personalised approach to adapting to a specific user or environment" [20] (p. 247). It makes it possible to both formalise [21] and democratise the design process [22]. The mass customisation approach within this paper is developed by using shape grammars to address the issues related to spatial design. The other aspects of mass customisation relating to this particular case—the organisational aspects of funding legal frameworks for establishing cohousing communities—are not discussed in this article for the sake of brevity.

The interest in developing formal methods in architecture can initially be traced to studies from the 1960s and 1970s. This is also linked to the fact that in the 1950s and 1960s, computers began to be introduced to universities [23], which later made it possible for researchers to execute various space-related modelling studies [24]. A number of authors contributed to the development of the field. Alexander [25] highlighted the need for a way of evaluating the form in context, without relying on a trial-and-error method, which is usually slow and expensive, and called upon researchers to replace this approach with a symbolic method. In 1971, Stiny and Gips [26] debuted the concept of shape grammars, presenting a formalism for the generation of non-representational, geometric paintings. This term is related to phase structure grammars, which were introduced by Noah Chomsky in linguistics [26]. In 1976, Hiller and his associates [27] described morphic languages that combine rule-governed creativity with the importance of syntax and the role of description in addition to the generation of structure. The aforementioned shape grammar research continued with the development of analytical shape grammars, such as the Palladian grammar [28], Frank Lloyd Wright's prairie house grammar [29], and the grammar of Queen Anne houses [30]. All three were aimed at using shape grammars to describe the design languages used by the original architects.

Shape grammars allow us to abstract architectural elements, translating them into simple shapes and assigning them dimensions, characteristics, and conditions for forming or transforming spatial compositions. The process can also be described as computing with shapes [31]. As explained by Stiny [32], shape grammars are a useful basic research tool for the development of a science of form. Because they are defined in terms of simplified shapes, they provide for the straightforward treatment of problems in formal composition. Two-dimensional shape grammars can be used for floor plan composition, and three-dimensional shape grammars can be used for characterizing component building systems. More generally, shape grammars provide a foundation for a theory of architectural composition [32].

The process allows for generating a wide range of possible spatial solutions while taking into account the selected criteria [33]. In this way, it allows for the generation of design alternatives, their comparison, and the evaluation of their quality and adherence to the user's wishes. The use of shape grammars can be seen as a paradigmatic approach to planning that is based upon the traditional use of case studies and that moves towards the use of systematic design principles instead of individual concepts. As a consequence of this approach, architectural knowledge about transformations that have taken place becomes explicit and transferable. Using these principles, we can work on developing an open methodology for generating spatial solutions for a specific problem, not only the examples of solutions themselves. They have a wide range of possible professional applications, but their research value lies in developing lateral thinking, forming various solutions to a problem simultaneously and allowing for the generation of unexpected solutions [34]. When dealing with renovation and adaptation projects, the grammar used to record the steps and changes is called a transformation shape grammar [35,36].

A shape grammar represents a set of rules applied step by step to a certain shape to generate a design. It is composed of an initial shape and shape rules describing its own design language. The shape rules work to add or take away shapes, and they can act as Euclidean transformations of translation, rotation, mirroring, and scaling. Labels that bear additional information or instructions that inform the design process can also be added. Shape grammars are not deterministic; their purpose is to generate a large number of design solutions based on a common design language that differ according to the decisions to apply different rules during the design process. They can therefore give us a variety of solutions, all adhering to a certain set of criteria that we choose to assign. The aim of a shape grammar is therefore to find more than one solution to a specific design problem [33].

For the functional renovation of existing buildings, we can employ the use of transformation shape grammars. Transformation grammars are used to adapt existing buildings to new requirements. They enable one specific dwelling to be transformed into another by applying transformation rules rather than generation rules, as used in an original shape grammar. In such cases, the initial shape can be the existing floor plan itself. A transformation grammar is used to create a systematic and methodical process that can encompass all the valid transformation rules for a given dwelling in order to satisfy the requirements stated at the outset [33]. Furthermore, a transformation grammar helps us track what changes when transforming one type of floorplan into another so that we can repeat them in similar situations, similarly to phrases in spoken language. This is how the technique can be used to learn from case studies performed on chosen building examples. The solutions can be transcribed as abstract transformation rules. This is the way in which a transformation shape grammar is inferred based on examples of existing spatial solutions that adhere to our chosen criteria and can be used to form a systematic planning tool. A transformation grammar for housing needs to be parametric due to the variety of shapes and dimensions of the rooms found in existing dwellings—it needs to be designed to identify rooms, walls, and spaces while taking several features into account [35]. Existing transformation shape grammar examples include Eloy's grammar for the Rabo-de-Bacalhau apartment blocks in Lisbon [37], Coimbra and Romão's grammar for the transformation of the Bourgeois House of Oporto [36], Guerritore and Duarte's Manifold Façades grammar for the adaptation of office buildings into housing [38], and Colakoglu's grammar for the interpretation and generation of vernacular Hayat houses in a contemporary context [39], with others emerging.

2.3. Research Design

The first stage of developing the shape grammar was to gather examples of single-family houses of varying types, located in different regions across Slovenia. This was carried out by the first author, partially on-site, by approaching the current house owners directly in person or by leaving leaflets in their mailboxes. The gathering was also supplemented via an online call for people to donate their floor plans. Some turned out not to be appropriate because laypeople sometimes misunderstood the concept of a type-house or provided incomplete plans.

The second stage involved obtaining several house transformation solutions to inform the corpus of designs and develop the shape rules. With this intent in mind, two workshops with architecture students were organised. The first workshop was held in May 2021 at the Faculty of Architecture, University of Ljubljana, and involved a group of 8 second-year architecture students, mostly affiliated with Design Studio Planiščček, working in pairs for five consecutive days. Four different houses from different regions were chosen to be transformed during the workshop. The brief for the transformation was given in the form of user profiles. Students were asked to design the transformations to fit three profiles of imaginary older people to help guide the exercise. Applying three different user profiles to four different houses produced 12 variations. In the second workshop, 18 more house examples were obtained, this time with the help of Design Studio Sadar at the Faculty of Architecture, University of Ljubljana, which had recently been analysing the subject. The studio had gathered the typical single-family house examples mostly from the student's relatives and were using them as a study exercise. To ensure that the number of houses would be manageable for the limited number of students attending our second workshop, 4 of the most representative types were chosen to introduce types with either two or three levels and different staircase and hallway positions. The second workshop involved 10 students of various stages, most of who were architecture students, but also involved an urban design studnets and an engineering student, who produced 10 variations over five consecutive days. This time, students were asked to focus more on the surrounding residential area, as well as the geographic context. Both workshops were organised and supervised by the authors, Ana Belčič and Sara Eloy, and were facilitated by Anja Planišček, Design Studio Planišček at the Faculty of Architecture, University of Ljubljana. Additionally, both workshops were introduced to the participants under the title "Redesigning Slovenian Single-Family Houses into Cohousing Communities For Older people" and had a similar, relatively condensed schedule, spanning one work week, from Monday to Friday. In both cases, the students were introduced to the concept of cohousing for older people through a lecture that concluded with a design brief for them to follow. The students developed their conceptual architectural solutions during the Monday and Tuesday and presented them on Wednesday morning. During this process, they were supervised and given any necessary further explanations or critiques by the organisers in the form of group sessions. On Wednesday afternoon, they were introduced to the basics of shape grammars through a lecture, followed by exercises and a lecture on inferring a shape grammar. Thursday was spent finalising the designs and working on shape grammar suggestions that the students developed themselves, attempting to detect and describe the shape rules they identified. On Friday, the workshops concluded with a final presentation and critique. After the completion of the workshops, the corpus of designs that the students produced was reviewed. Due to the fact that many had been designed by younger students in a very short time span, their work had to be edited in order to comply with standards of accessibility and minimal dwelling standards. The editing and re-drawing process was carried out by the first author. Examples included editing the bathroom sizes, the passages and turning radiuses for wheelchairs, the lift dimensions, and other needed edits. Some solutions or partial solutions had to be modified, combined, or scrapped completely. As a result, from the corpus of eight houses that were used in the student workshops, five were chosen to be used for inferring the shape grammar. This choice was made to ensure that the grammar was based on the most typical examples that would be highly transferable. The houses were chosen in order to represent the different compositions seen in the analysed houses—the ones with straight, U-shaped, or L-shaped staircases, placed in the middle of the house or on the side, as well as both two-storey and three-storey houses. The criteria, therefore, involved finding real house examples that would make sure that all the common compositions were represented in the grammar. The three houses that were not used in the end were eliminated due to the fact that two turned out to be too small to house a group of older people comfortably and that one was much larger than most and had less typical structural/spatial proportions, producing less transferable results. After the process of editing and re-drawing the selected solutions, 15 variations designed for 5 different houses were chosen to serve as the basis for the shape grammar.

2.4. Research Approach—Analysing the Corpus of Designs

Some examples of analysing the solutions and determining transformation rules were attempted by the students attending both workshops. In the first workshop, the students were asked to find a common space function classification system for the 12 solutions they produced and use it to record the transformations that took place within them (Figure 4).

In the second workshop, they were given the freedom to develop their own shape grammar system for each of the 4 different houses and the solutions developed for them, resulting in some interesting propositions (Figures 5 and 6).

The shape grammar systems proposed by the students could not be used directly in the final grammar due to changes in the selected corpus of designs and subsequent editing; however, their work provided an interesting set of ideas for the classification of space functions and the problem of working with multiple floors in a single building. Analysing the corpus of designs intended for constructing the shape grammar in this study was therefore based on the 15 edited solutions, as shown in Figure 7.

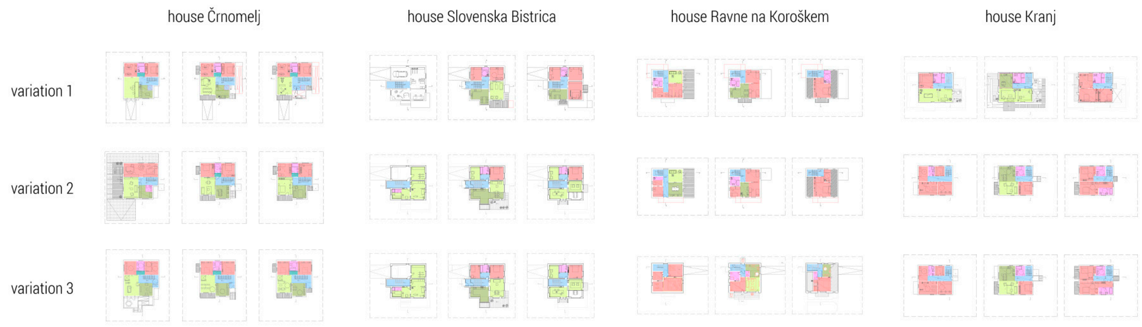


Figure 4. The 12 floor plan solutions, to four houses in different locations, obtained during the first workshop. The space functions were colour-coded by the students. Authors: attendees of Student Workshop 1, 2021.

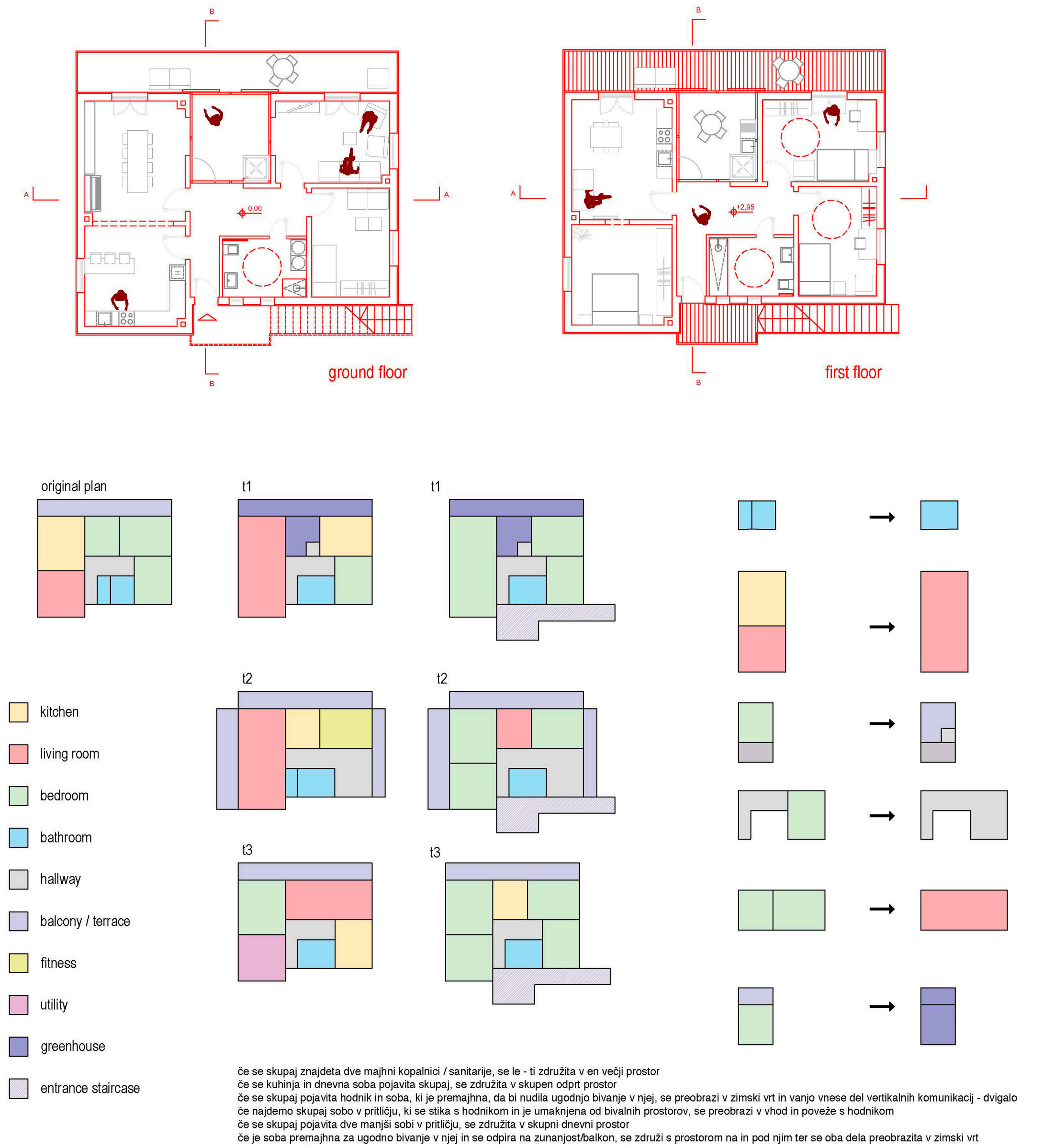


Figure 5. An example of the shape grammars developed by the students. Authors: attendees of Student Workshop 2, 2022.

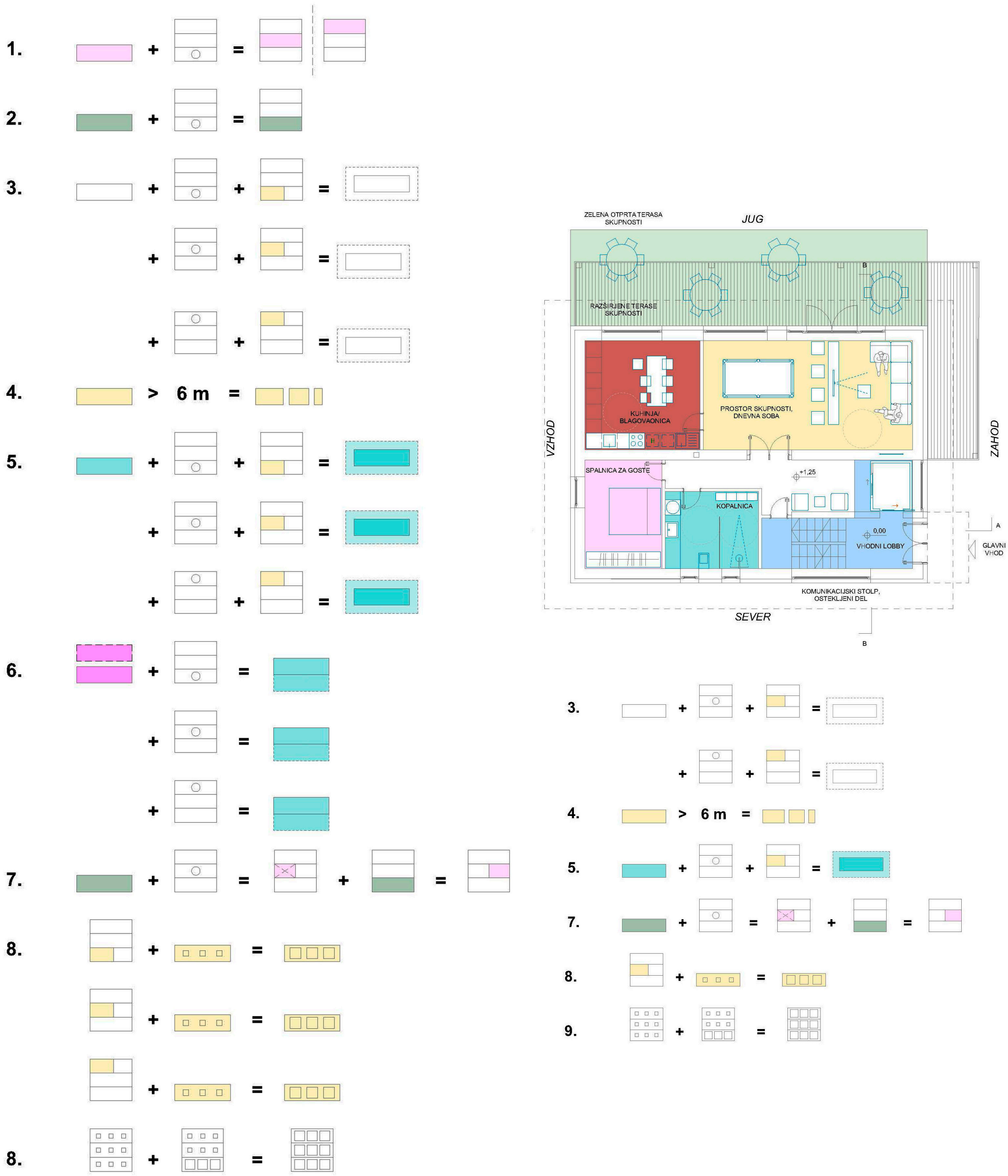


Figure 6. Another example of the shape grammars developed by the students. Authors: attendees of Student Workshop 2, 2022.

2.5. Inferring the Shape Rules

Inferring all the transformation rules involved a process of cataloguing all the transformations that took place in every floor plan, sometimes with multiple attempts. This was used not only to determine the rules but also to try and test the possible sequence of their application, as shown in Figure 8. During this process, the classification of space types changed to some degree, and therefore, as the list of rules was evolving, so was the classification of spaces, in order to organise both into a comprehensive grammar.

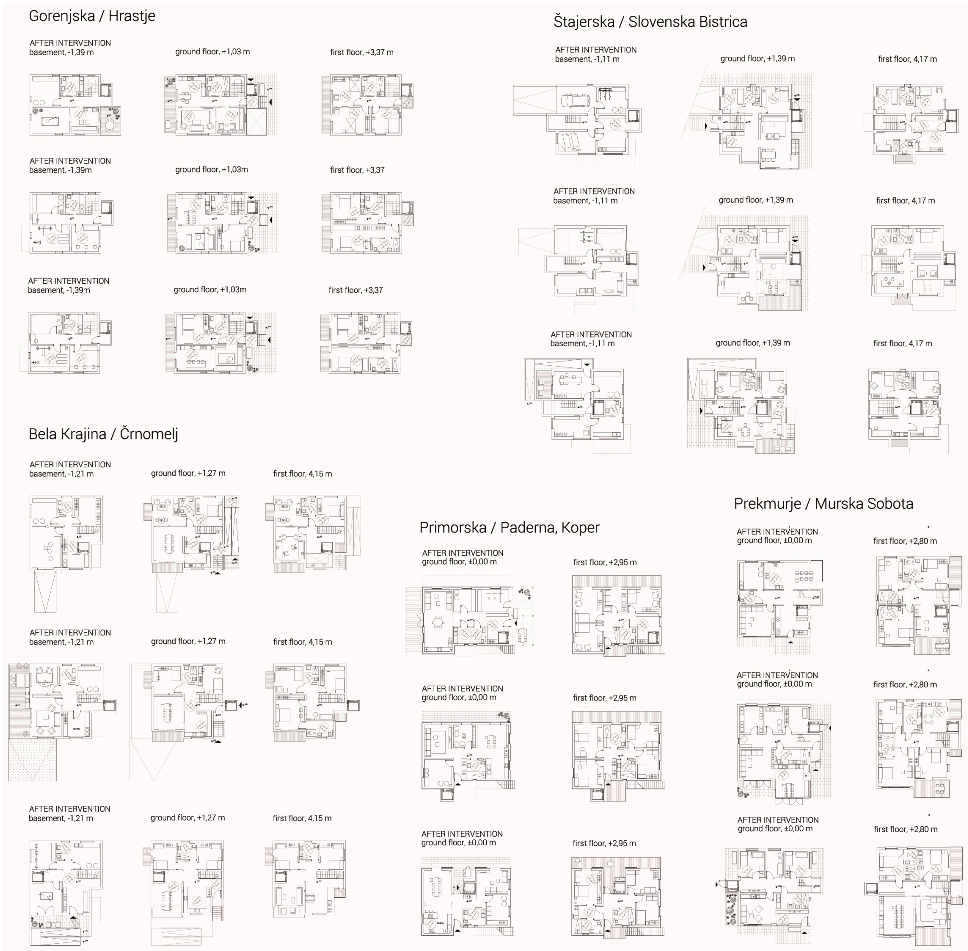


Figure 7. The corpus of 15 solutions designed for five different type-houses in different locations (Ana Belčič, 2022).

Figure 8. Cataloguing all the transformations in order to infer the transformation rules (one of the working versions) (Ana Belčič, 2022).

3. Results

3.1. Shape Rules

3.1.1. Transformation Rules

Inferring the transformation rules required cataloguing the transformations that took place. In the classification of space functions, we aimed both to keep track of the changes of use and to make sure that all the essential spaces were assigned when generating the floor plans in the application and testing phases. The existing floor plans were marked to denote livable spaces, usable spaces, sanitary spaces, halls, staircases, terraces/balconies, and garage ramps (Figure 9). We used both colour coding and written labels to mark the space functions. Livable spaces included all spaces that had an adequate ceiling height and enough sources of light to be used as permanently inhabited spaces (rules 24–43). Usable spaces (mostly located in basements) denoted spaces that could not be permanently inhabited but could be used for certain temporary activities (rules 13–23). Sanitary spaces were marked to take into account the spaces that already had plumbing.

Figure 9. Existing floor plans with the classification of space functions (Ana Belčič, 2022).

A systematic overview of all the transformations regarding the function of the space was organised (Figures 10 and 11). The first 12 rules determined that the existing spaces of a specific function could keep their function—for example, an existing hall, Sxh, can remain a hall in the new layout, and is therefore assigned the label Sh. Similarly, existing sanitary spaces, Sxs, can remain sanitary spaces and can become one of the following: a full bathroom, a toilet, a full bathroom with a laundry room, or a toilet with a laundry room. Rules 13–43 determined what transformations of existing space functions into new space functions were allowed to occur.

The list of rules was then organised into groups according to the nature of the transformation taking place. The groups include:

- Rules for re-using space functions 1–12 (Figure 10);
- Rules for transforming existing space functions into new space functions 13–43 (Figures 10 and 11);
- Rules for swapping space functions 44–55 (Figure 12);
- Rules for merging and splitting 56–84 (Figures 12 and 13);
- Rules for transforming full bathrooms into en-suite bathrooms 85–86 (Figure 14);
- Rules for extension, subtraction, and insertion 87–97 (Figure 14);

- Rules for determining entrances 98–99 (Figure 14);
- Rules for lift positioning 100–112 (Figure 15);
- Rules for addition and removal 113–114 (Figure 15); and
- 3D rules 115–126 (Figures 16 and 17)

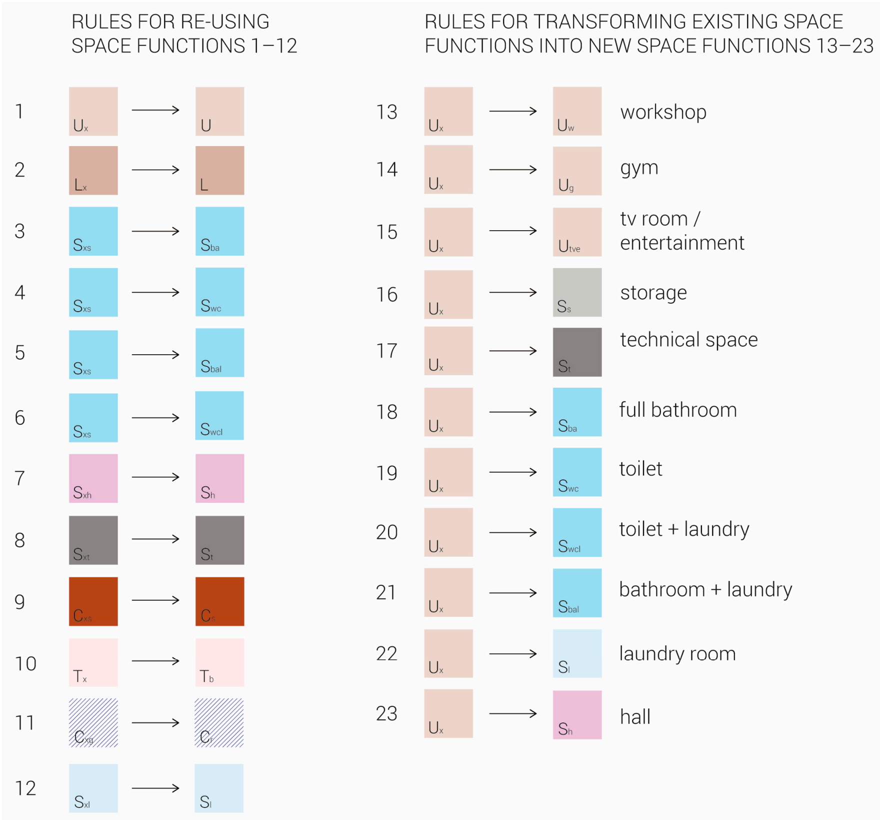


Figure 10. Rules for re-using space functions 1–12 and rules for transforming existing space functions into new space functions 13–23 (Ana Belčič, 2022).

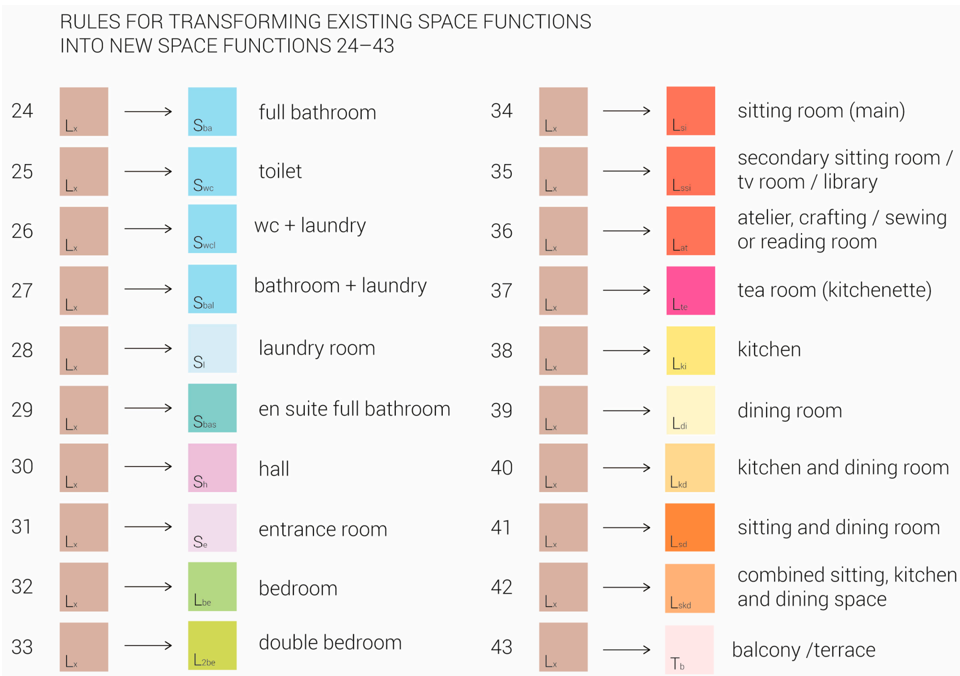


Figure 11. Rules for transforming existing space functions into new space functions 24–43 (Ana Belčič, 2022).

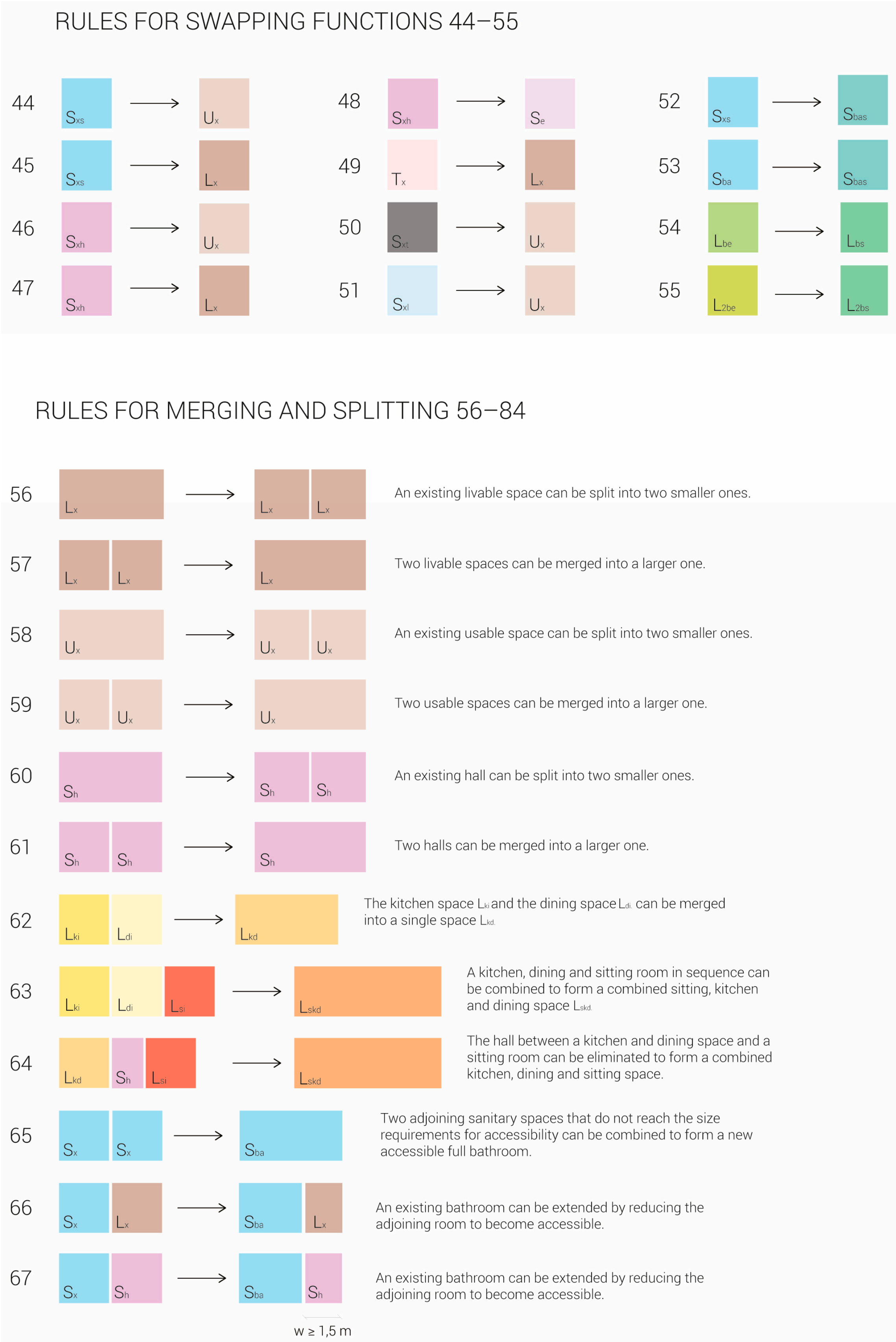


Figure 12. Transformation rules 44–67 (Ana Belčič, 2022).

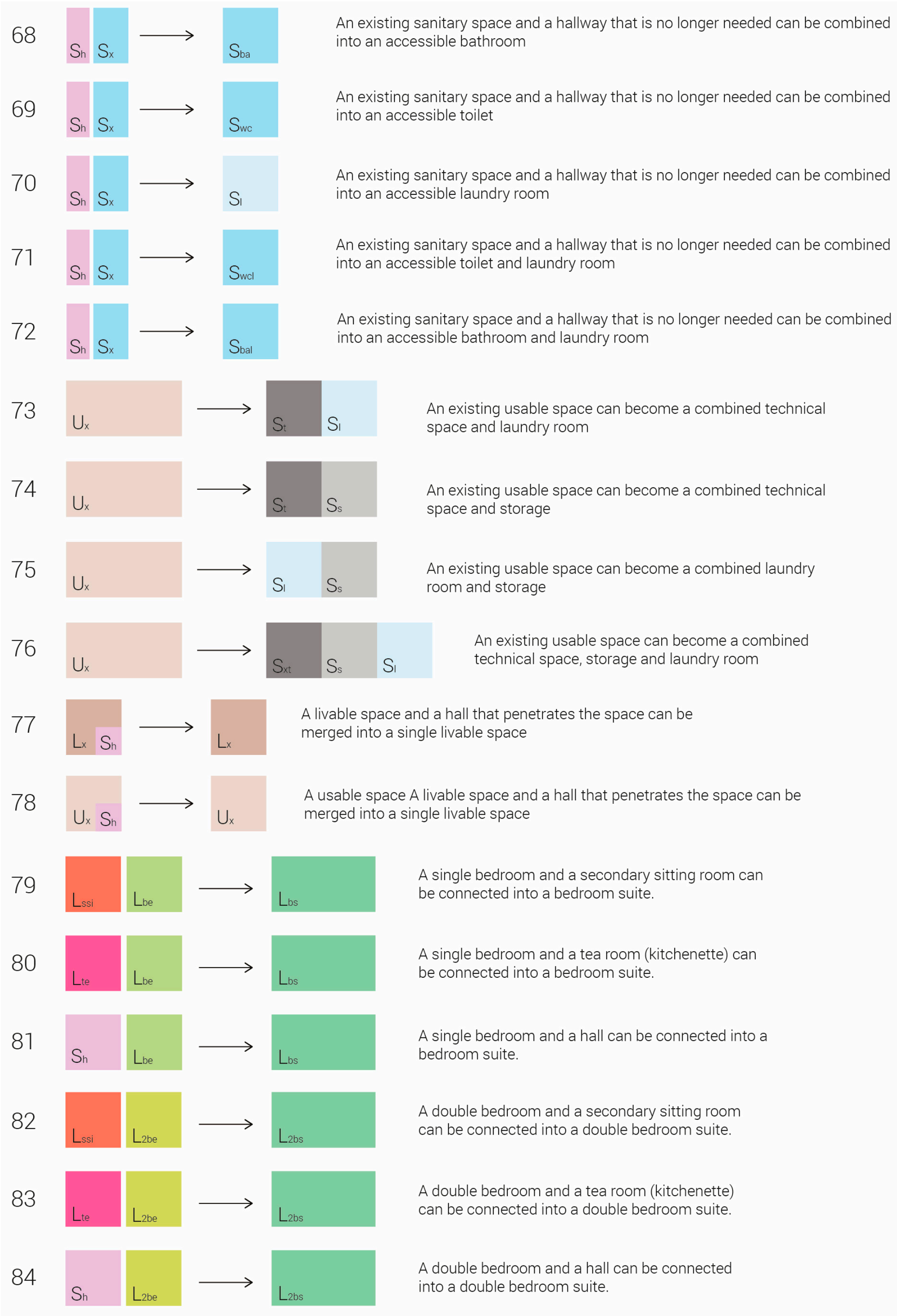


Figure 13. Transformation rules 68–84 (Ana Belčič, 2022).

Additionally, sets of rules were identified that could help speed up the generation process by providing a pre-existing combination of spaces for generating bedroom suites.

Assigning the lifts (Figure 15) required additional conditions to ensure that they led into communal spaces and never landed in, for example, a bedroom or a bathroom. This meant that transitional spaces needed to be determined.

The rules that were inferred were mostly in 2D form; however, some required 3D application to fully inform the transformation (Figures 16 and 17). This was especially important in the case of lifts that could, obviously, only be applied as a 3D rule that connected all the levels in a single vertical space—as described by rules 115, 116, and 117.

Figure 14. Transformation rules 85–99 (Ana Belčič, 2022).

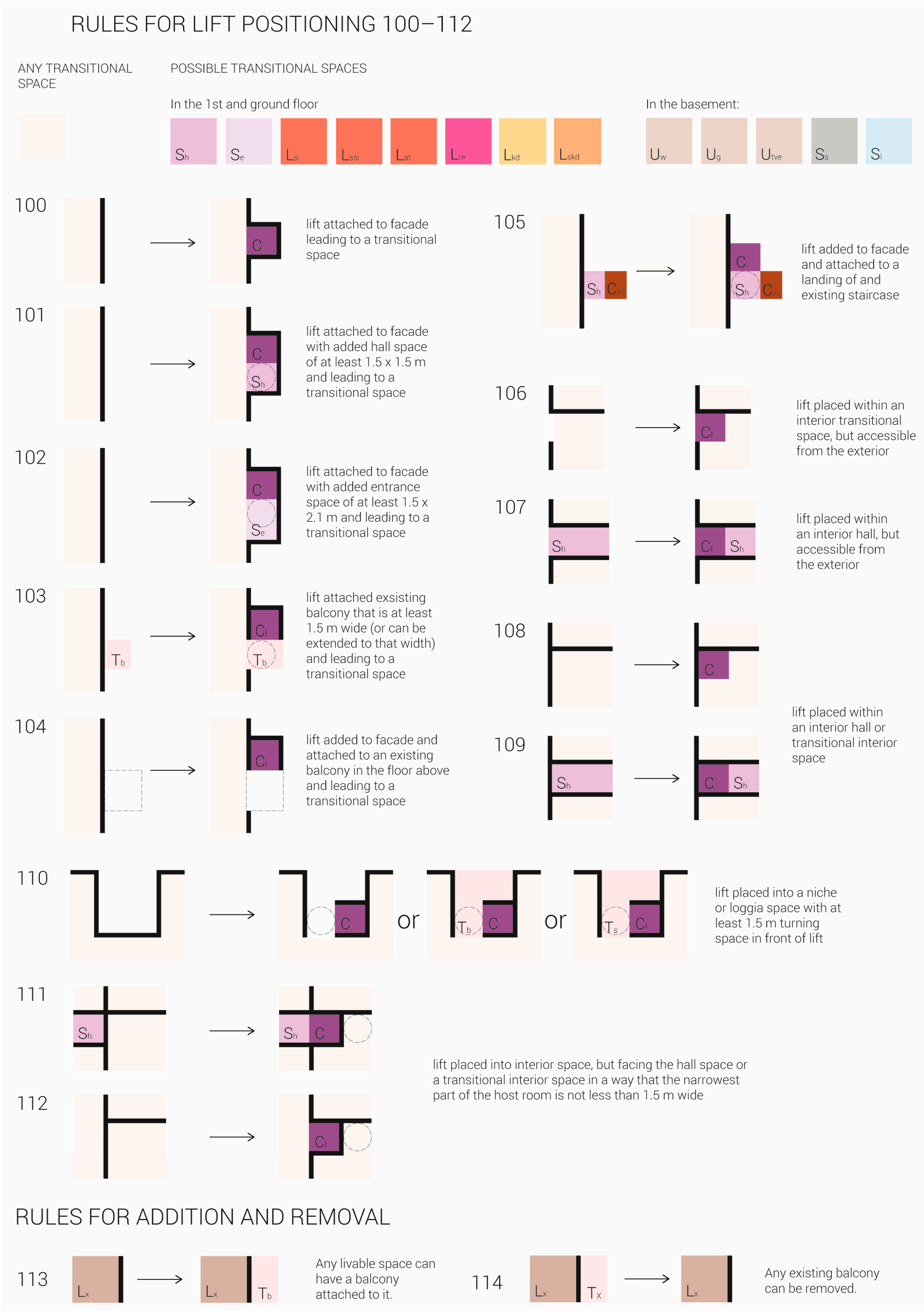


Figure 15. Rules for lift positioning and rules for their addition and removal (Ana Belčič, 2022).

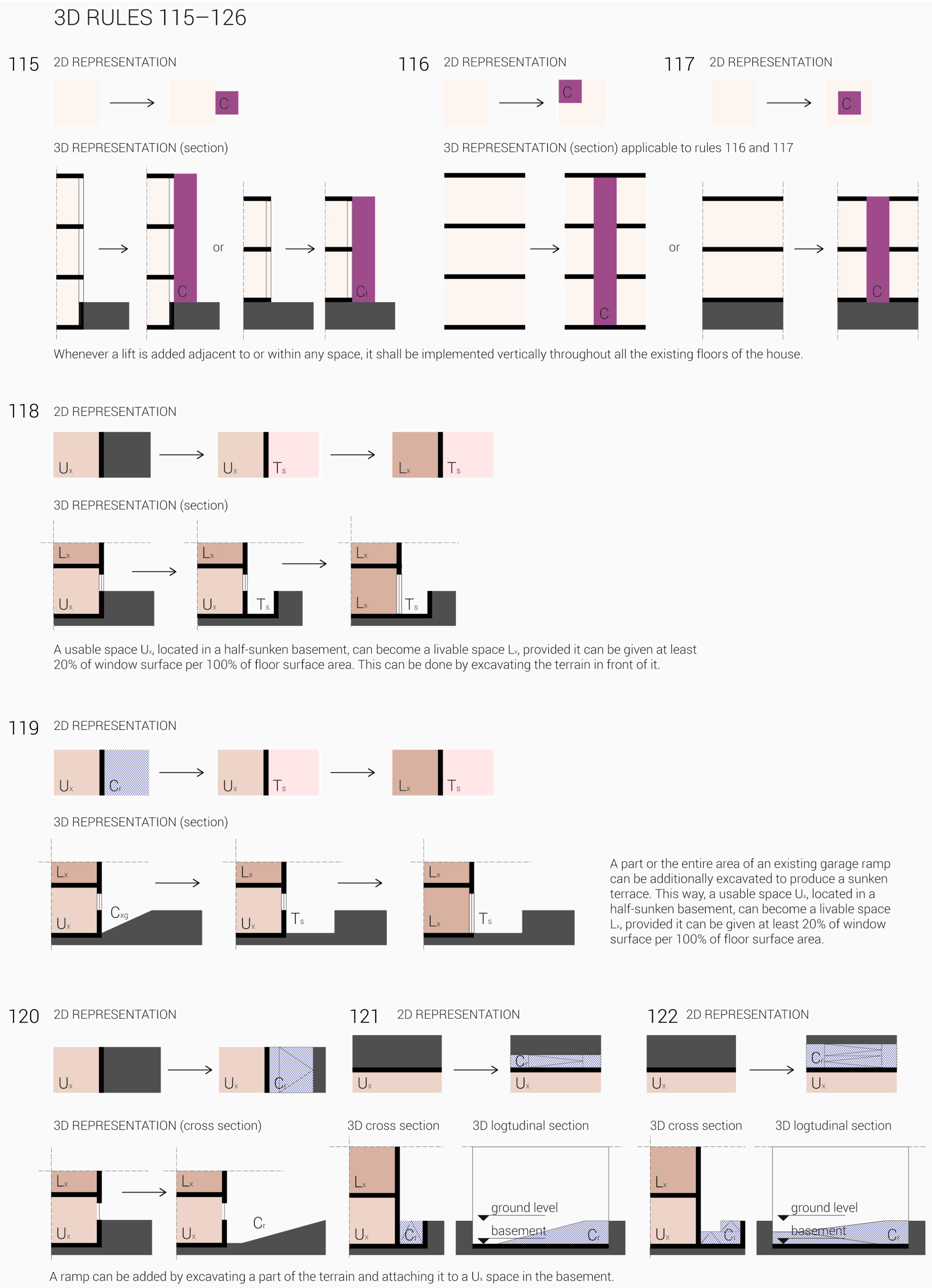


Figure 16. 3D rules 115–122 (Ana Belčič, 2022).

The 3D rules that involved excavating a part of the surrounding terrain could cause some of the usable spaces in the basement to be transformed into livable spaces and could therefore be assigned the functions of communal spaces (rules 118, 119, and 120). In this case, the semi-subterranean space would receive a sunken terrace and additional windows, making it suitable for more permanent habitation. Another option is removing the space slab between the ground floor and the basement using rule 123, resulting in a double-height space. These spaces could not, however, contain bedrooms.

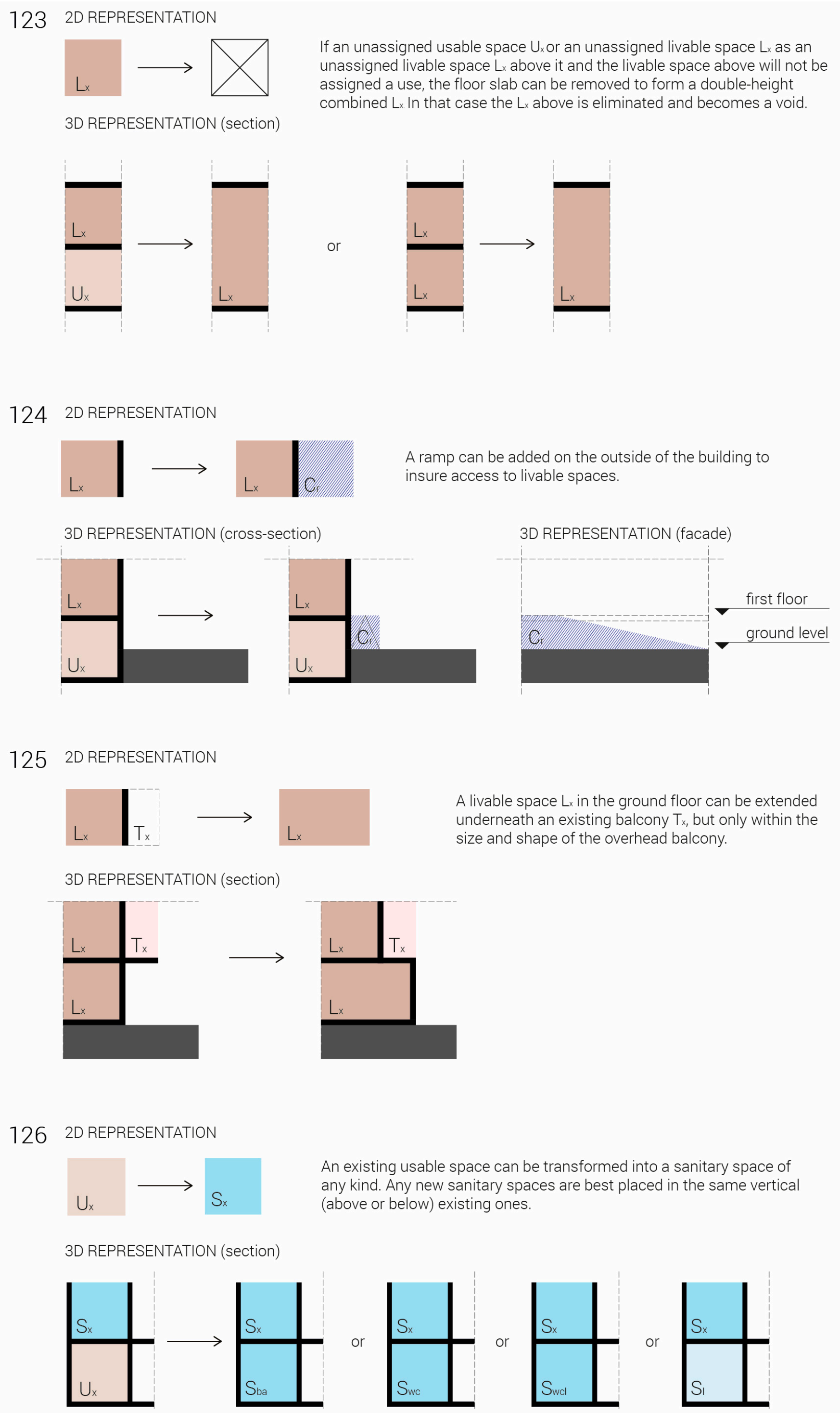


Figure 17. 3D rules 123–126 (Ana Belčič, 2022).

3.1.2. Space Requirements

Rules for specific spaces had to be equipped with a list of requirements for determining their dimensions, ratios, and other characteristics according to the number of users. Naturally, a household with six or five people needs to have more kitchen and dining space than one with four inhabitants. Determining these requirements was carried out by using both the minimal dwelling standards guide that is in use in Slovenia, paired with recommendations for wheelchair users and other people with reduced mobility. To ensure that the dimensions and layouts truly produced useful spaces, a catalogue of possible compositions was extracted from the corpus of case study solutions (example—Figure 18).

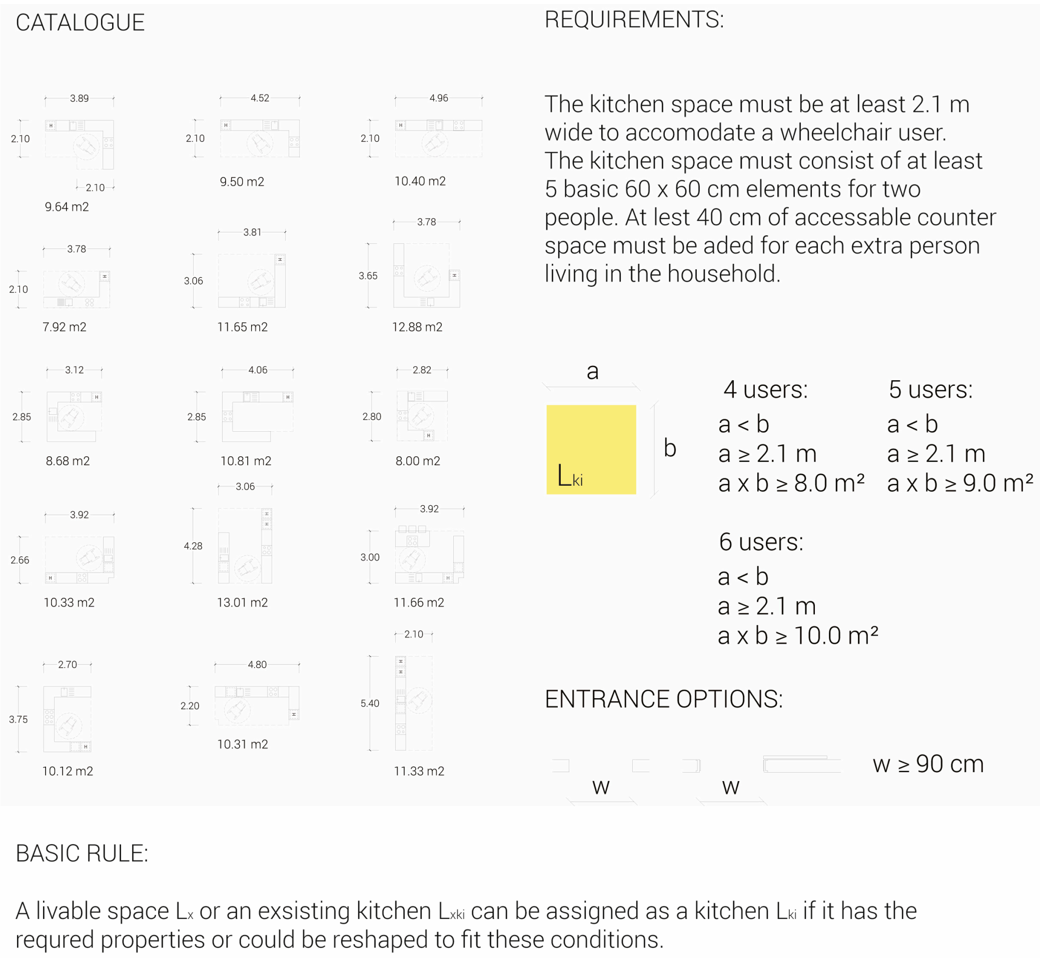


Figure 18. Kitchen requirements (Ana Belčič, 2022).

3.1.3. Sets of Rules

Due to the fact that certain spaces were required to be positioned adjoining other spaces, particularly in the case of bedroom suites, a set of rules combining different rooms was added to help catalogue the possible compositions that could be employed and speed up the derivation process (Figure 19). Sets of rules were identified based on case study examples.

3.2. Strategies

3.2.1. Detecting and Describing the Strategies

After analysing the corpus of designs produced by the students, it became evident that in general, three strategies were employed to transform the houses (Figure 20). Strategy 1 involves splitting the house into two parts on a horizontal axis, separating the first floor from the ground floor (and basement, if present) into two separate areas. The first floor thus becomes the sleeping and private area, whereas the ground floor becomes the living and communal area. This strategy can, for example, be applied in cases where the entire ground floor has great potential for being connected to the garden and the surrounding community in at least three directions. Strategy 2 involves splitting the house on a vertical axis, generating a sleeping and private half and a living and communal half on both the first floor and the ground floor. An obvious reason to use this strategy presents itself when the location has specific orientation features that might improve the quality of the lived experience within it. For example, focusing the bedrooms and bathrooms in the eastern part of the building while opening the communal spaces towards the west would ensure good lighting throughout the day in the spaces where people meet and interact. Another way to use this strategy could help to orient the quieter, more intimate part of the house away from the noise of the street, while opening the communal part of the house towards passers-by. Of course, the opposite is also possible, if the house allows it and if the potential inhabitants would find that preferable. The private bedrooms can face the street to allow for people-watching and stimulation, whereas the communal spaces can retreat to the back to have a more cosy, intimate feel. Strategy 3 is only applicable to houses with three levels, where the basement can also be partially transformed into a liveable space, as it requires a maximum amount of private spaces. The entire first floor and one half of the ground floor are dedicated to private areas in this case. The common spaces can therefore be placed in one half of the ground floor and a liveable space in the basement.

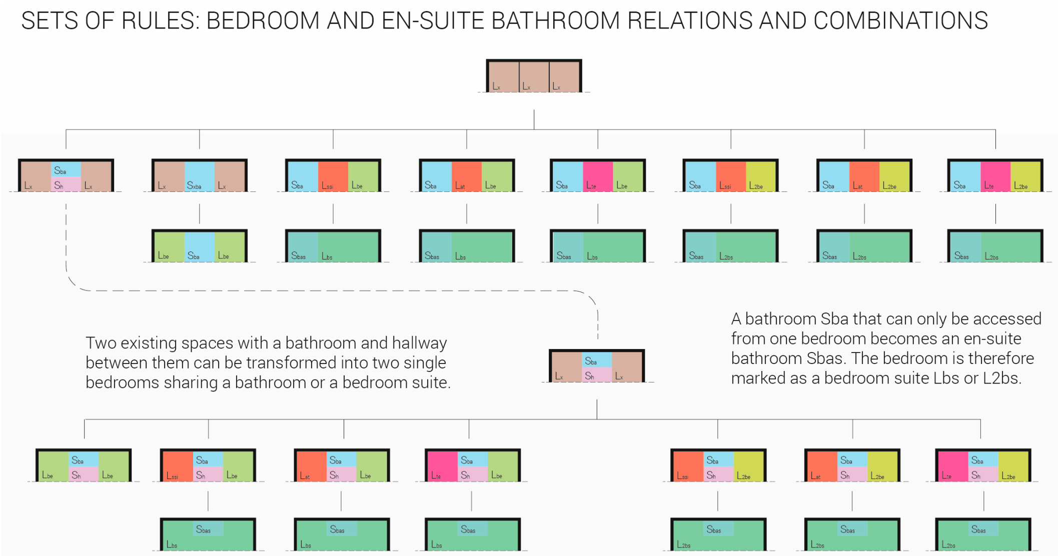


Figure 19. Sets of rules that can be employed to transform three adjacent rooms into bedroom suites (Ana Belčič, 2022).

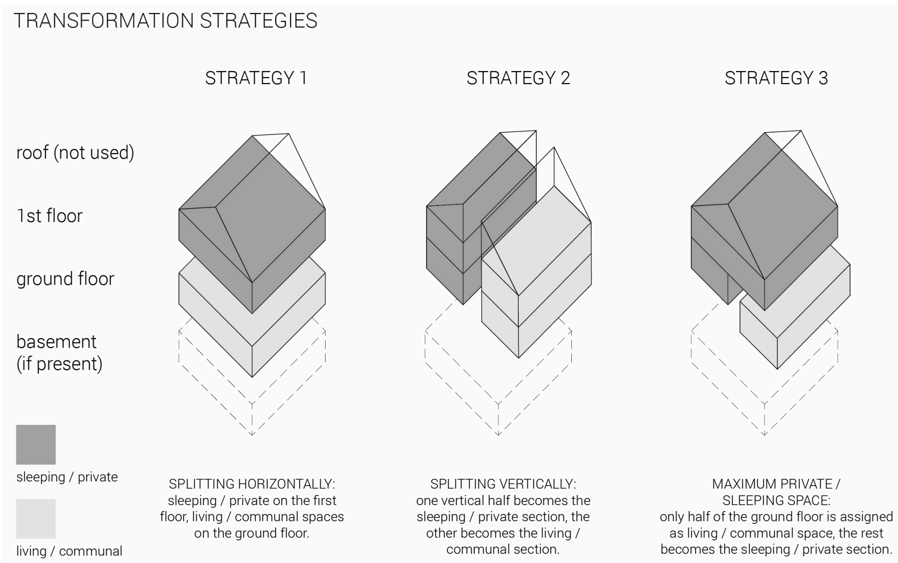


Figure 20. A conceptual representation of strategies 1, 2, and 3 (Ana Belčič, 2022).

3.2.2. Transformation Sequences

First Floor Transformation: For the design process to be self-generating in any way, there must be a clear starting point. Before starting the transformation, one of Strategies 1–3 must be chosen to guide the generation process step by step. Strategies are needed to ensure that all the floor plans are generated in a way that makes them compatible and ensures that all the essential spaces will be represented and placed correctly. In the case of Strategies 1 and 3, the entire first floor is designed in order to provide a maximum number of bedrooms, bathrooms, and/or bedroom suites.

In the case of Strategy 2, the floor plan is divided in half, with one half being assigned to private spaces (bedrooms, bathrooms, and bedroom suites) and the other half being assigned to some of the obligatory common spaces (the kitchen, dining room, or sitting room). The chosen approach seemed to be the most efficient way to begin the transformation of the first floor of the house. This allowed the design process to begin by determining the sleeping and communal spaces, assigning the bedrooms first as their role is more important in generating the composition. Whenever a bedroom is assigned, an accessible bathroom must be assured in its vicinity. There can be a maximum of three single bedrooms assigned while the overall composition only has one bathroom. If there are four single bedrooms, an extra bathroom must be assigned; otherwise, the fourth bedroom must be omitted and can become a common space instead. Each space that is assigned must also have a door opening assigned to it with a width corresponding to the type of door that is being used. A swing door, for example, requires a greater wall width on the side where the door handle is located in order for a wheelchair user to access it and open the door with ease.

Ground Floor Transformation: As a result of the 3D rule for assigning the lift being used, the position of the lift is already assigned to the ground floor. This means that the space adjoining the lift can only become a transitional space. The ground floor plan also requires an entrance to be assigned. Similarly to the lift, the entrance can be placed in a manner that leads to a transitional space.

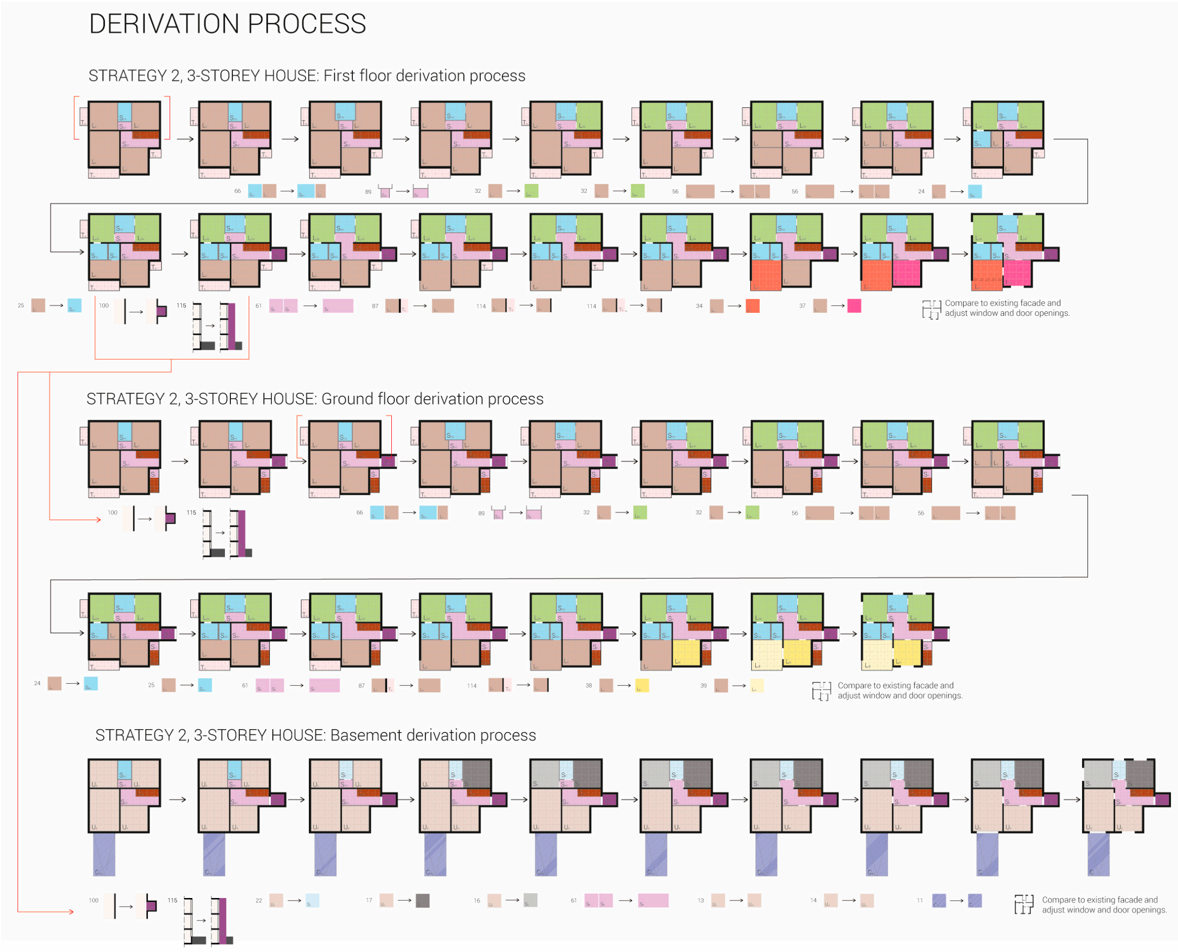
In a house with two levels, the ground floor must also contain the obligatory service spaces—a technical space, a laundry room, and a storage space. These can be combined into one room of at least 15 square meters if needed.

In the case of Strategy 1, all the obligatory common spaces (the kitchen, dining room, or sitting room) must be placed on the ground floor. In the case of Strategy 2 or Strategy 3, the floor plan is again divided in half, with one half being assigned to private spaces (placed underneath the half used for private spaces on the first floor) and the other half is assigned to some of the obligatory common spaces. In Strategy 2, the full bathroom is assigned first and the bedrooms are placed adjacent to it. Additionally, in Strategy 2, the assigned common spaces need to be the one or ones not yet assigned on the first floor. In Strategy 3, not all of the common spaces need to be assigned to the ground floor, as some of the common spaces can also be moved to the basement if at least one of the rooms of a suitable size can be transformed into a liveable space.

Basement Transformation: As on the ground floor, the 3D rule for assigning the lift also determines the position of the lift in the basement. Basement spaces cannot become liveable spaces unless they undergo specific transformations determined by the transformation shape grammar (rules 118, 119, 120, and 123). They can, however, contain usable spaces, such as a gym or a workshop. In a house with three levels, the basement must contain the obligatory service spaces—a technical space, a laundry room, and a storage space. In this case, they can be combined into two rooms if needed.

3.3. Demonstration

To illustrate the generative ability of the inferred grammar, the transformation rules were applied to the house examples following the chosen strategy's transformation sequences, demonstrating the validity of the study. The derivation process was carried out manually. An example of the derivation process is presented in Figure 21 (below).



FIRST FLOOR PLAN

(1.) Split the floor plan in half using the part with an existing sanitary space first.

(2.) Improve exsisting sanitary space size if needed and assign a full bathroom.
An adjoining hall space can be improved right after this step to improve accessibility.

(3.) Assign bedrooms:

a) Assign single bedrooms and at least one bathroom.
b) Assign bedroom suites containing en-suite bathrooms.

There must be at least one bathroom per two people. Additional sanitary spaces can be provided.

Move to the remaining half:

If the existing hall has contact with the facade, all spaces can be used as bedrooms or bathrooms. If there is no such connection, one of the spaces will be used to house the lift;

(4.) Assign lift positioning:

a) If the existing hall has contact with the facade, attach a lift to it.
b) If the hall has no contact with the facade, assign a space to house the lift.

(5.) Improve the hall size if needed.

(6.) Resize, transform or add terraces.

(7.) Assign a kitchen and dining space or a sitting room space to the remaining space/s.

(8.) Compare new plan to the existing facade and adjust window and door openings.

GROUND FLOOR PLAN

(9.) Assign lift position corresponding to the one in the first floor.

(10.) Split the floor plan in half corresponding to the first floor plan.

(11.) Improve existing sanitary space size if needed and assign a full bathroom.
An adjojning hall space can be improved right after this step to improve accessibility.

(12.) Assign bedrooms:

a) Assign single bedrooms.
b) Assign bedroom suites containing en-suite bathrooms using composite rules.

There must be at least one bathroom per two people. Additional sanitary spaces can be provided.

Move to the remaining half:

(13.) Improve the hall size if needed.

(14.) Resize, transform or add terraces.

(15.) Assign a sitting room space or kitchen and dining space to the remaining space/s, depending on what was already assigned to the first floor.

(16.) Compare new plan to the existing facade and adjust window and door openings.

BASEMENT FLOOR PLAN

(17.) Assign lift position corresponding to the one on the first floor and the ground floor.

(18.) Assign laundry room.

(19.) Assign technical space.

(20.) Assign storage space.

(21.) Improve the hall size if needed.

(22.) Assign any remaining spaces freely.

(23.) Compare new plan to the existing facade and adjust window and door openings.

Figure 21. Floor plan derivation process for Strategy 2, 3-storey house—one of the variations shown in Figure 22 (Ana Belčič, 2022).

In Figure 21, Strategy 2 was applied to one of the chosen house examples. Due to the fact that multiple ground-floor plans can fit multiple first-floor plans, the number of possible variations was further extended. For example, the first-floor plans used in Strategy 1 could often be used in Strategy 3 as well. Similarly, ground-floor plans designed for Strategy 2 could be used in Strategy 3 compositions. Figure 22 illustrates 59 variations of the design space of the presented transformation grammar in order to act as a proof of concept, but this does not mean that the generation process was limited to that number—the process was stopped in order to save space. The floor plans that could fit together are indicated with the use of a connecting dark blue line beneath the diagrams.

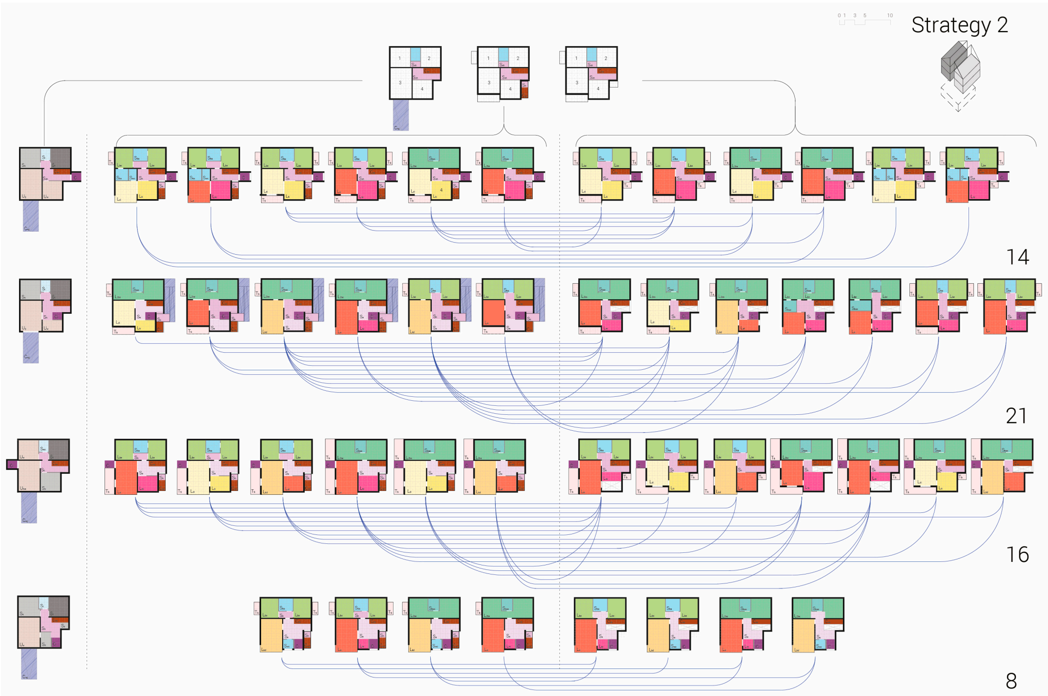


Figure 22. 59 composition variations obtained using Strategy 2 (Ana Belčič, 2022).

4. Discussion

After finalising the workshops and the shape grammar, it became evident that in future work, a set of preparatory rules would be useful in order to simplify the floor plans. Therefore, to ensure the easy application of transformation rules, an initial simplification of floor plans was proposed post festum in order to aid the generative process. Rules were developed to be applied to the existing floor plans to eliminate elements that might be distracting in the work process. The resulting category of rules was referred to as the preparatory rules and included rules 0.1–0.11 (Figure 23).

This category included rules for removing non-loadbearing partition walls that enclosed spaces smaller than two square meters, as well as rules for removing partition walls that did not define a hall or a sanitary space. In this approach, we also chose to disregard any existing wall openings, such as doors and windows, within the preparatory phase. Interior doors would be determined when assigning new space functions. Windows and external doors can be addressed when finalising the floor plan generation exercise. This way, they could be placed in order to best fit the new floor plan, while attempting to keep as many openings as possible in their original place. The latter was intended to act as a cost-reducing feature that would also simplify the adaptation process.

The study was, however, limited by the fact we were working with the resources available and could therefore not have access to solutions provided by, for example, a larger number of designers or more experienced designers. The transformation shape grammar is a method that relies on the input it receives from the corpus of designs gathered and analysed by the authors, which means that more variations and additional rules could be developed by a more diverse group of designers. It is possible, however, to refine the result presented in this research with more data at any time.

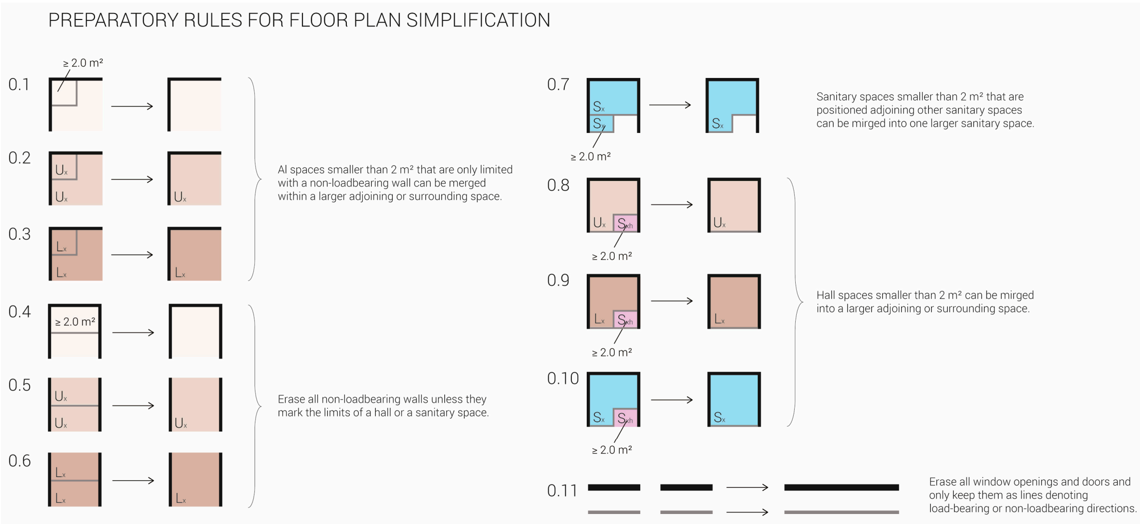


Figure 23. Preparatory rules (Ana Belčič, 2022).

In terms of its approach, the system presented in this study can be compared to some pre-existing shape grammars, such as Eloy's transformation shape grammar for adapting "Rabo-de-Bacalhau" apartment buildings [37] regarding the theme of reusing and reshaping existing housing facilities. On the other hand, it deals with a 3D environment, since it addresses up to three floors that need to be transformed to work in unison, which is somewhat similar to Duarte's grammar for generating new house designs in Siza's Malagueira [20]. However, the grammar described in this study had to resolve some complex problems unique to its case, which also led us to expand upon the existing methodological approaches. The fact all the buildings had to be equipped with a lift (that could also be installed at a later date, according to the inhabitant's needs) posed another challenge that had to be addressed with a combination of 2D and 3D rules which were utilised at specific points in the transformation sequence. The most daunting difficulty of the task lay in the fact that in this case, the shape grammar had to be adapted in such a way that would allow it to work with a varied collection of existing house types.

5. Conclusions

Our investigation showed that typical single-family houses were in many cases flexible enough to be transformed into a wide variety of different architectural solutions corresponding with the needs and desires of the users and their micro-locations and the contexts in which they were located. In general, the exercise demonstrated that transformation shape grammars that combined both 2D and 3D rules for guiding interventions could become a useful tool for planning the functional layouts of small housing communities for older people. The simplification of spaces into shapes with a defined set of requirements makes it possible to review a large number of compositions and determine the most fitting solutions for the intended users and the context in which the house is located. This could aid in the revitalisation of ageing residential areas as a whole.

The shape grammar presented here represents a research exercise that is comprehensible when used by other architects who are familiar with the concept of shape grammars. This is, however, not the final goal of the research. We aimed to develop a method that could support mass customisation, in order to empower the future users of these houses, the aged residents, in the design process. In future research and development, the process would ideally be computerised, rather than performed manually, to increase the speed of the derivation process, as well as to make it more accessible to non-architects. Therefore, an interface to communicate with the future users of the houses in a more efficient way needs to be developed. Since there is a multitude of simple and free floor-plan-drawing software options available, which could potentially be utilised and merged with the shape grammar generator, it remains to find a representation technique that is suited to the final users—older people. This could potentially be achieved by testing various interface graphic styles working in an easy-to-use application, program, or online generator that older people would find comprehensible and intuitive.

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