The Inference of Generic Housing Rules: A Methodology to Explain and Recreate Palladian Villas, Prairie Houses and Malagueira Houses

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Abstract This paper describes the setting out of generic housing rules. These rules were synthesized using a grammar formalism as described in previous papers. This study focuses on the parametric shape rules and its application.

Generic grammars were applied in works such as the urban generic grammar for the purpose of describing urban patterns. However the application of generic grammars to other scales has not been performed to date. A generic grammar is a formalism that allows the design of a diverse solutions, unlike a typical grammar which focuses on a specific design language. This work analyzed three languages: Palladian villas, Prairie and Malagueira houses and proposed a single grammar to replicate the examples. This work will showcase the set of generic rules and the strategy used to parameterize each shape rule. The contribution of the work lies in the way each rule is parameterized to cater for each language whilst the shape rule remains the same.

Introduction

This research paper describes the structure and set of generic shape rules of a generic shape grammar applied in housing. The grammar comprises eight stages: the first stage arranges the boundary setting out; the second is responsible for the spatial subdivision; the third stage wall thickening; the fourth stage the functional

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assignment; the fifth stage the creation of adjacencies by connecting door creation; the sixth stage responsible for window design; the seventh stage boundary; and finally the eighth stage the termination with the deletion of labels. For the production of this generic grammar the previous comparative and analysis work was fundamental to set the standards and foundations.

We consider a generic grammar to be a grammar that allows the generation of a set of designs from multiple styles rather than defining a particular feature or style. If different shape grammars each recreate only a particular design corpus all of them are independent; however, a more generic description covering a number of separate grammars would allow relationships to be seen between them. A similar analogy can be placed to describe spoken languages, which is the analogy that inspired in the first place the idea of shape formulations. If several languages have separate and distinct grammars but in many cases share a common ground, and if some distinct languages also share simple phrase constructions, then a higher level grammar can be elaborated to describe that branch of languages.

In this instance an attempt was made to create a shape grammar that would encode the parameters required to design three types formerly considered independent: the Palladian villas, the prairie houses and the Malagueira houses. A new grammar that represented the different types was recreated, by considering the sequence of grammar rules and incorporating parametric functions. The grammar proposed does not fit the criteria of an unrestricted type of grammar because it implies an ordered structure and rule ordering process and clearly presents restrictions [6]. Knight (as quoted by Prats [9]) classified the three types of grammars as Additive, Grid and Subdivision. This grammar should be used intelligently if not assisted by a computer program. The function of buildings raises another issue. The question of typology and use constitutes a key factor in the choice of corpora, simply because different uses cannot be relevantly compared (e.g., housing and retail). Therefore, taking into account shape grammars that were previously inferred and available, and the relevance, program and type of use, housing seemed to be a good candidate.

An analysis was performed on three shape grammars selected with regards to bottom-up approach, containment of external fabric and type of grammar. The grammars were classified not only by the number of occurrences of shape rules but also by the rules that help design the house basic features. In the Palladian grammar the first stage and first nine rules determine the basic house layout. These rules help design a grid that will set standard for the spaces later detailed. In the Prairie houses the first third of the grammar allows for additive rules followed element by element to design the house. This is generated in a progressive way and the house grows in detail and in size. The Malagueira type showcases a radically different approach. The first steps are additive but soon change, such that all later rules related with spatial creation are subdivision rules, by which space is designed by sub-dividing a generic space and then detailing a portion by assigning function.

Once the grammar type is determined the type of house label is considered. Most of the house types selected coincide with the notion of single detached housing isolated in the plot (Malagueira is mostly semi-detached). Nevertheless, and regardless of the detachment condition, some of these houses are self-contained and packed within an external boundary and others are not inscribed or not contained. The first case of compact or contained houses are present in all house types studied.

This paper is composed of three sections. The first section reflects on the methodology used to create the generic rules and its parameterization, followed by a section that describes the validation process and the conclusion section where the results are discussed and future work described.

Methodology

A case study was selected among three different single housing languages: Palladian villas, Prairie and Malagueira houses. Previous work demonstrated how these pre-existing grammars were analyzed and their combined rule set derived [1, 2]. The most frequent rules were extracted and identified as generic rules.

The methodology is based on three tasks: the development of generic shape rules, the creation of a generic grammar formalism and lastly the development of specific parameterization to represent different languages. The strategy used to create the generic grammar followed certain principles:

1. Top-down approach
2. Self-contained strategy based on a polygonal boundary
3. Subdivision as a method to provide detail
4. Common shape rules to address the generation process
5. Variation and detail conferred by the parameterization in each shape rule

The first stages of design creation have a greater level of abstraction while the latest promote specific detailing. In addition the first stages propose a more abstract formulation where only the house floorplan outline is illustrated and the latest stages confer specific detail.

The generic grammar developed proposes a total of eight stages.

As illustrated in, Fig. 1, the first stage is prompted by the incorporation of the polygonal boundary. This boundary and its proportions vary from language to language but at this point a great range of de-signs is allowed. Stage 2 promotes subdivision. With subdivision the first zoning exercise takes place and the first spaces are created. Sub-division is a process commonly used in housing design. Its use is intuitive and prescriptive and for that reason was chosen as primary meth-od of design in the generic grammar. Stage 3 focuses on space merging or concatenation, allowing adjacent rooms to be merged creating different geometries. Stage 4 provides wall thickening by an offset process. The original abstract lines are doubled according to the tectonic nature of the housing language.

These four stages constitute the common branch and the true generic body of the grammar. This level of abstraction can be easily observed since the design at this point is still mono dimensional and representative. It is not conferred with wall

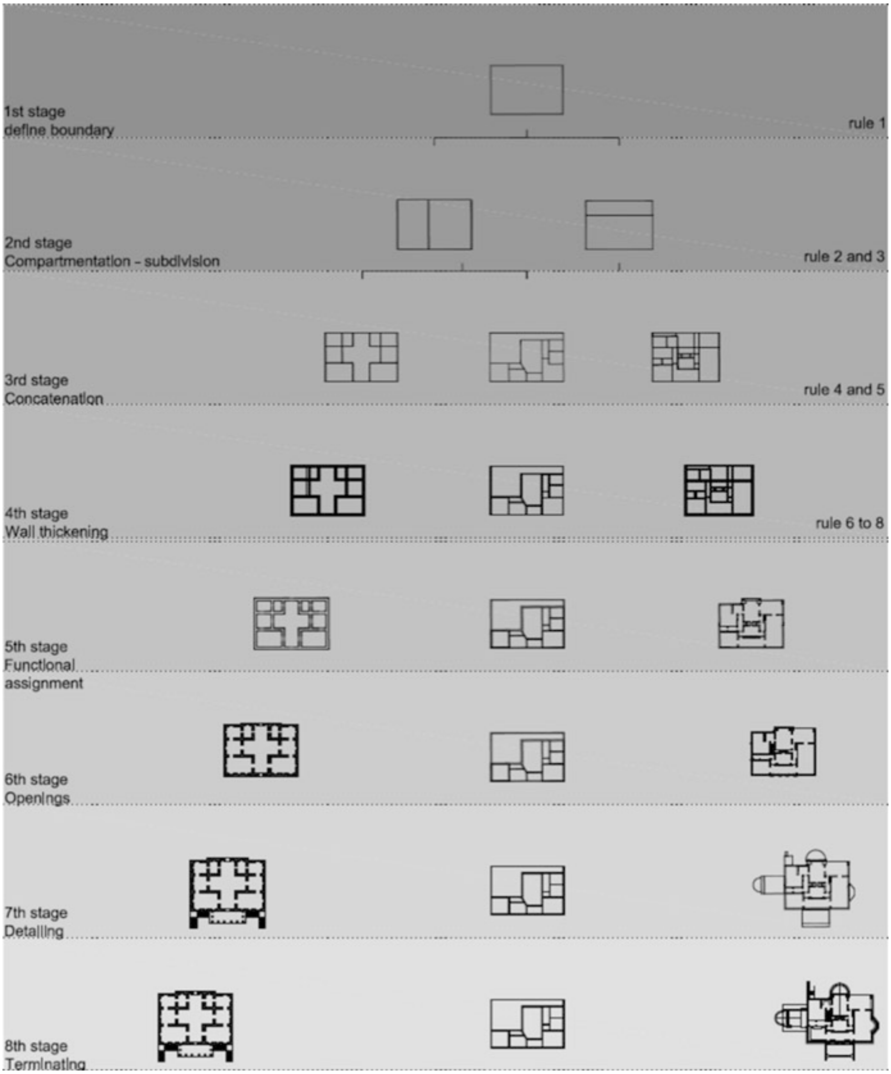


Fig. 1 Generic grammar tree diagram

thicknesses, openings or functions. It is a simple representation of a schematic house floorplan.

Stages 4–8 propose similar formulation but are specific to each language and have particular shape rules—the attempt has not yet been made at generic rules for these. Respectively they are: stage 5 functional assignment, stage 6 inclusion of openings, stage 7 detailing, stage 8 completion.

The diagram below illustrates the application of the generic grammar. The common branch is clearly illustrated on top with a similar containing shape branching out to three district solutions. Illustrated on the left, the Palladian villa 'la Malcontenta', in the middle the Malagueira house type Ab as described by Duarte [4], and on the right the Winslow prairie house by Frank Lloyd Wright.

The tree diagram shows the application of the generic grammar to replicate three different house languages, all of them part of the pre-existing corpus of the styles. It illustrates how each solution can be created and developed in order to effectively describe an output of each language.

The development of generic shape rules involved the observation and synthesis of some of the most common shape rules used by grammarians. Previously inferred shape grammars focused on particular languages of design such as the Palladian villas [10], the prairie houses [7], the Malagueira houses [5], the Wren city churches, buffalo bungalows and Queen Anne houses to name a few.

From a structural point of view these grammars follow either a grid, addition or subdivision methodology.

Despite the differences between the discussed grammars with regard to their structure and top-down or bottom-up approach, all rules can be reduced to a set of shape rules that obey either addition, subdivision, concatenation, subtraction or replacement.

Previous work showed how these rules are applied showcasing various differences but expressing a similar essence [1, 2]. This can be represented by schemas (as introduced by [11]). Schemas try to trans-pose the graphic description into a simple algebraic expression. This allows for a certain level of abstraction while applying a rule. Schemas represent the shape rule without using graphical symbols. Often grammar users get stuck into a graphical representation and restrict the use of a particular rule but its abstract notion can avoid these misconceptions.

So for the four rules identified a specific schema is proposed:

1. Addition:

$$\emptyset \rightarrow X$$
$$X \rightarrow X + t(X)$$

2. Subdivision:

$$X \rightarrow \mathrm{div}(x)$$
$$X \rightarrow \mathrm{prt'}(x) + \mathrm{prt''}(x)$$
$$(X' + X'') \rightarrow \mathrm{prt}(b(X' + X''))$$

3. Concatenation:

$$(X' + X'') \rightarrow X$$
$$\mathrm{prt'}(x) + \mathrm{prt''}(x) \rightarrow X$$

4. Subtraction:

$$X \rightarrow X - \text{prt'}(x)$$
$$(\text{prt'}(x) + \text{prt''}(x)) \rightarrow \text{prt'}(x)$$

In addition to the identified generic rules specific parameterization was developed. Along with the graphic representation and each schema the parameterization for each rule was specifically developed to cater to each language. In this study three languages were used as case studies, which led to three different expressions with particular variables catered for each language. This constitutes the novelty of this generic grammar and what allows the generic rule to work when applied particularly to each family of solutions. The generic shape rules and their parameterization are clearly presented in Table 1. Exemplified are stages 1–4 and rules 1–8 which constitute the common branch. For each generic shape rule a common graphical representation is pro-vided and a specific algebraic expression presented for each language of the case study: Palladian villas, Prairie and Malagueira houses. A good example of the addition rule is rule 1. This rule introduces the first shape into the design. This shape follows a specific parameterization presented for each one of the three styles. This first rule showcases how the expressions work. The graphical rule introduces a rectangular boundary defined by the width (x) and height (y). The Palladian villas adopt specific rectangular ratios, commonly 2:3, 3:4, 3:5 and others predefined by the language. On the other hand Malagueira houses apply a specific fixed ratio that defines the available house plot of 12 × 8 m (a 2:3 ratio). This first generic rule (boundary addition) constitutes an example of an addition rule with a standard schema ø → X. The parameterization is then targeted to provide the correct areas, ratios and proportions of each style. It is evident from Palladio's extensive descriptions, drawings from 'Il Quattro libri' and observation of the existing corpus that the Palladian villas allow ratios of 1:1, 3:2, 4:3, 3:5, 4:5 and 3:7.

This mandatory rule will be used by all types and therefore the labels PAL, PRA, and MAL will be applied symbolising respectively Palladian villa, Prairie or Malagueira house. This parametric rule designs a X × Y rectangle with specific formulations and ratios for each type as described by the rule schema:

$$\emptyset \rightarrow X$$

To an existing shape X, you introduce a new shape that can translate a transformation on the initial design stage:

$$X \rightarrow X + t(X)$$

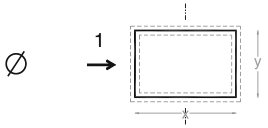
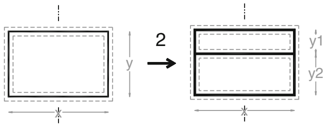
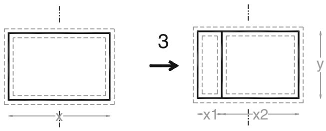
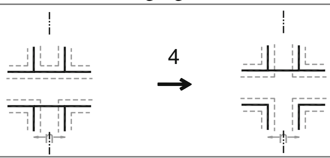
Respectively:

PAL: $y/x = n/m \rightarrow m = [3,5,7] \rightarrow n = [2,3,4,5] \rightarrow$ allowed ratios: 1:1, 2:3, 4:3, 3:5, 4:5, 3:7

PRA: [x, y]

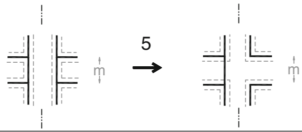
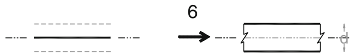
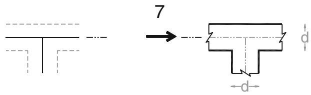
MAL: $X = 8$ m, $Y = 12$ m $\rightarrow$ allowed ratio: 2:3

Table 1 Generic grammar shape rules

Stage 1	Boundary definition	
Rule 1	Adding boundary	Parameterisation
Palladian villas		Y/X = N/M
		M = [3, 5, 7]
		N = [2,3,4,5]
		Permitted ratios: 1:1, 2:3, 4:3, 3:5, 4:5, 3:7
Prairie houses		[X, Y]
Malagueira houses		X = 8 M
		Y = 12 m
		Permitted ratio: 2:3
Stage 2	Spatial subdivision	
Rule 2	Horizontal subdivision	Parameterisation
Palladian villas		Y/X = N/M
		M = [3, 5, 7]
		N = [2,3,4,5]
		Y = Y1 + Y2
		Y1 = Y/N V Y1 = Y/3n
		Y1 = Y2 (for N = 2 V N = 4)
Prairie houses		[X, Y]
		Y = Y1 + Y2
Malagueira houses		Y1 = Y2 = Y/2 V
		Y1 = N X Y/4 N = [1–4]
Rule 3	Vertical subdivision	Parameterisation
Palladian villas		y/x = n/m
		m = [3, 5, 7]
		N = [2,3,4,5]
		X = 2.X1 + X2
		X1 = N V X1 = 3.N/2 V X2 = 2n
		Y1 = Y2 (For N = 2 V N = 4)
Prairie houses		[X, Y]
		X = X1 + X2
Malagueira houses		X1 = X2 = X/2
Stage 3	Space merging	
Rule 4	Horizontal merging	Parameterisation
Palladian villas		X = N
Prairie houses		
Malagueira houses		
Rule 5	Vertical merging	Parameterisation
Palladian villas		Y = m
Prairie houses		

(continued)

Table 1 (continued)

Malagueira houses		
Stage 4	Wall thickening	
Rule 6	Single wall	Parameterisation
Palladian villas		$D \approx 2$ vicentine feet
		$D = 600$ Mm
Prairie houses		D Ext $\approx 100 + 1/4$''
		D Int = 100''
Malagueira houses		D Ext ≈ 250 Mm
		D Int = 200 Mm
Rule 7	Wall 'T' junction	Parameterisation
Palladian villas		$D \approx 2$ vicentine feet
		$D = 600$ Mm
Prairie houses		D Ext $\approx 100 + 1/4$''
		D Int = 100''
Malagueira houses		D Ext ≈ 250 Mm
		D Int = 200 Mm
Rule 8	Wall corner junction	Parameterisation

The same principles apply for the subdivision rules. The graphical representation of rules 2 and 3 describe the generic subdivision rule. Both rules propose subdivisions thereby allowing diverse solutions. The allowance of the subdivision process is conditioned by the parameterization. The prairie houses impose particular restrictions which confer symmetry. The 'vertical subdivision' is ruled by the bi-symmetrical principle imposed on the floorplan, and therefore the subdivision is replicated symmetrically. On the other hand floorplans like the Malagueira obey specific proportion ratios such as 1:2, 2:3 and 3:4.

The second stage is responsible for the basic layout of the house floorplan. This stage proposes four shape rules. Half of the rules proposed are subdivision rules and are responsible for the generation of great part of the house fabric. The reminder are merging rules that deal with particular conditions and help designing spaces with more complex geometries by spatial concatenation. Shape rule 2 is responsible for the horizontal subdivision. This type of subdivision can be placed in any of the three house types and allows the creation of two separate spatial/functional zones by splitting the space horizontally. Regardless of the house type the rule schema can be represented by the following expressions:

$$X \rightarrow \mathrm{div}(x)$$

$$X \rightarrow \mathrm{prt'}(x) + \mathrm{prt''}(x)$$

$$(X' + X'') \rightarrow \text{prt}\,(b(X' + X''))$$

Therefore the resulting rule parameterisation can find intervals in:

$$N : [x, (y' + y'')]$$

Similarly rule 3 is responsible for the creation of two separate spaces using a subdivision method. The difference lies in the direction of the split, in this case placed vertically. In normal circumstances the rule could be equally applied for the three case scenarios, however the Palladian villas pose some singularities which require special address. The issue of symmetry patent in the Palladio language requires that a vertical split has to be performed and copied symmetrically across the floorplan using the North to South direction as an axis. Therefore the rule has to allow for the proper parameterisation of this case.

$$N : [(x' + x''), y]$$

Or in the Palladian grammar:

$$N : [2.(x' + x''), y] \ldots$$

The concatenation rule is represented on the third stage by rules 5 and 6. These represent a space merging operation by the deletion of one border. This rule is commonly used by designers to generate spaces with a certain degree of geometric complexity and is used frequently in grammars (ref). This rule which uses a schema similar to $\text{prt}'(x) + \text{prt}''(x) \rightarrow X$ allows several specificities such as the parameterisation proposed in Table 1.

The latest stages propose language specific shape rules. The development of parameterisation caters to particular housing detailing features. Within these rules can be found:

1. Particular features for Palladian language
2. Particular features for Prairie language
3. Particular features for Malagueira language

Derivation

The recreation of three original designs from start to finish by the phased application of the shape grammar rules is illustrated in Figs. 2, 3, 4, and 5. In this experiment three existing houses designed by the original architects were selected to illustrate the generic grammar. Villa Malcontenta is an example of a typical Palladian villa, the Winslow House, one of Wright's most famous creations, illustrates the existing corpus of Prairie houses and the Malagueira two-bedroom

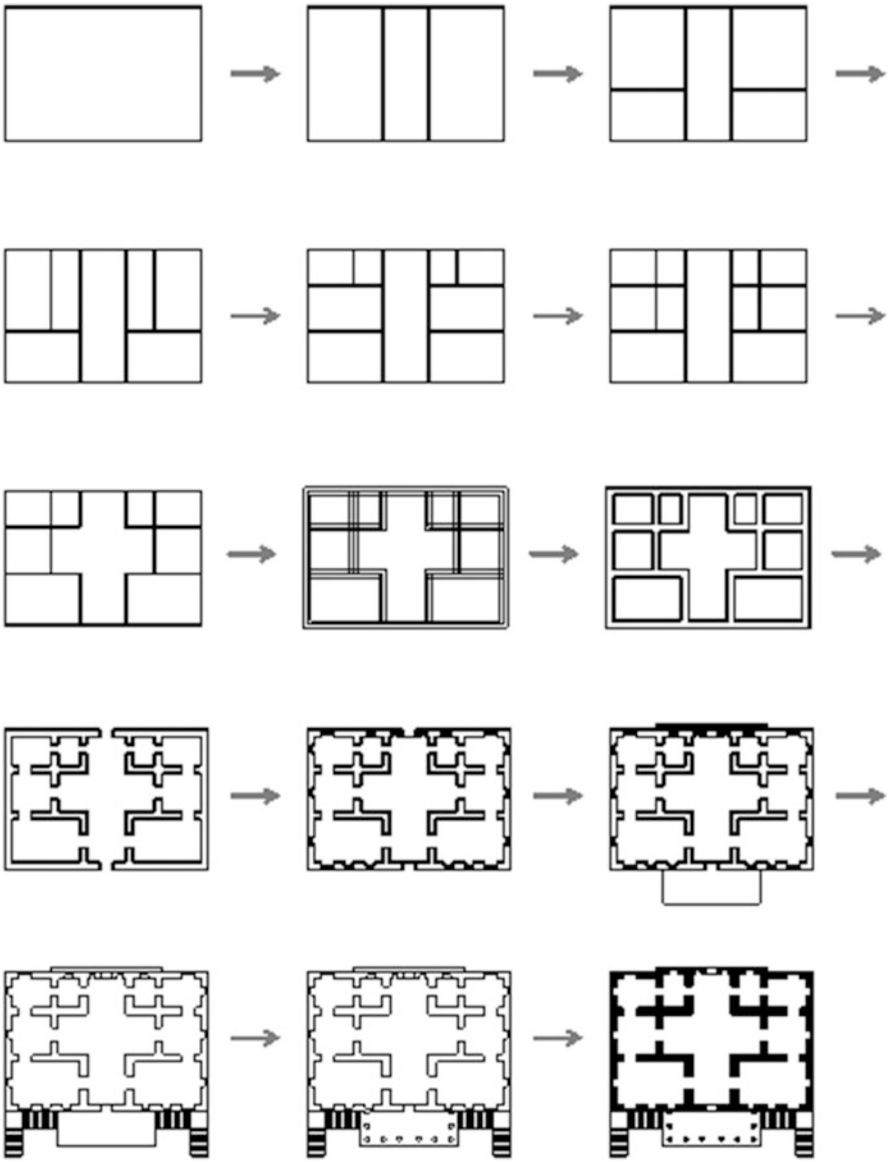


Fig. 2 Generic grammar derivation – Palladio's Villa La Malcontenta

Ab type house (according to Duarte's labelling) exemplifies a typical Malagueira family housing unit [5].

La Malcontenta, Fig. 2), was originally designed, built and completed in Venice's outskirts between 1559 and 1560 and is pictured in the 'Il quatro libri' [8]. Its orthogonal features and grid-like floor plan features a matrix that resembles

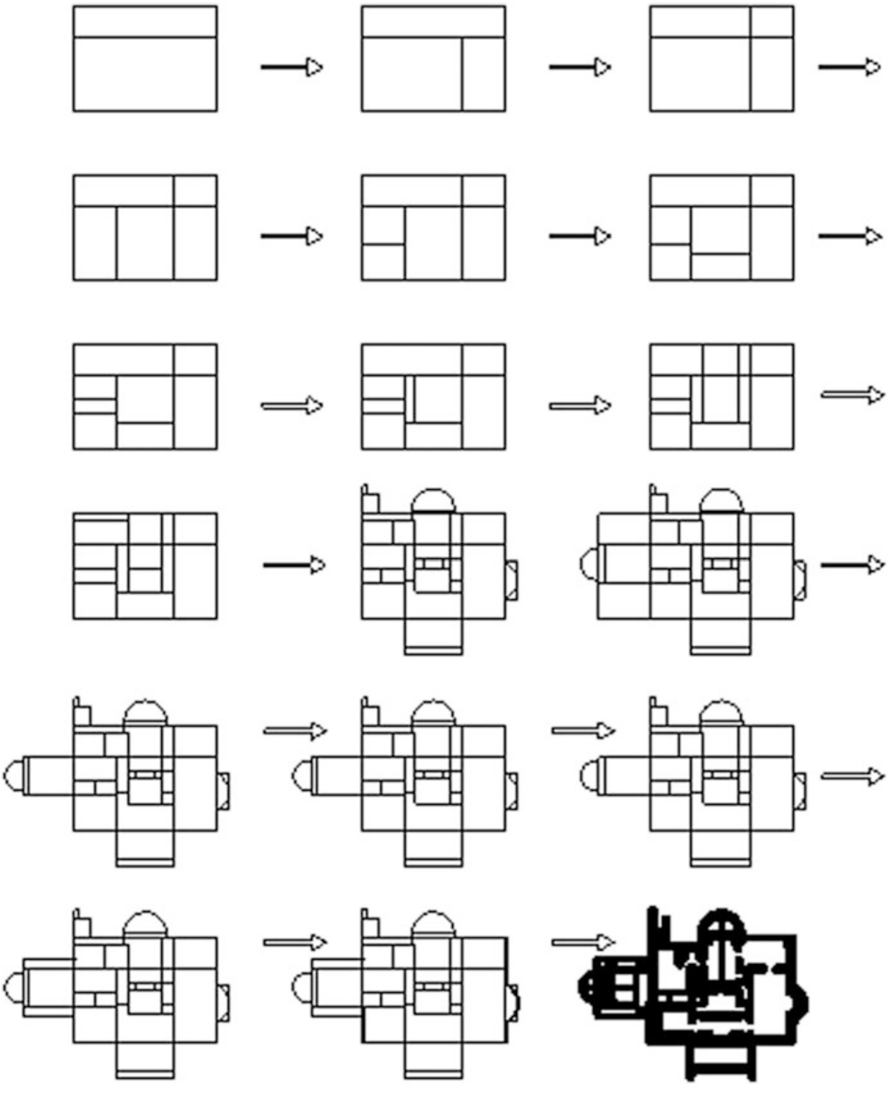


Fig. 3 Generic grammar derivation – Prairie Winslow house

a 5×3 grid organisation. Whereas the original grammar used a grid process, achieving the same design with subdivision allows us to economise on certain steps (namely extensive concatenation). The envelope is thus designed and established from the start. As shown, this subdivision is doubled to address the symmetrical nature of the design. Steps 3–6 use the division rules 2 and 3 recursively (in the case of Rule 3, repeated again and again). Steps 7 and 8 start the space merging or concatenation process. This is a fundamental step for spatial

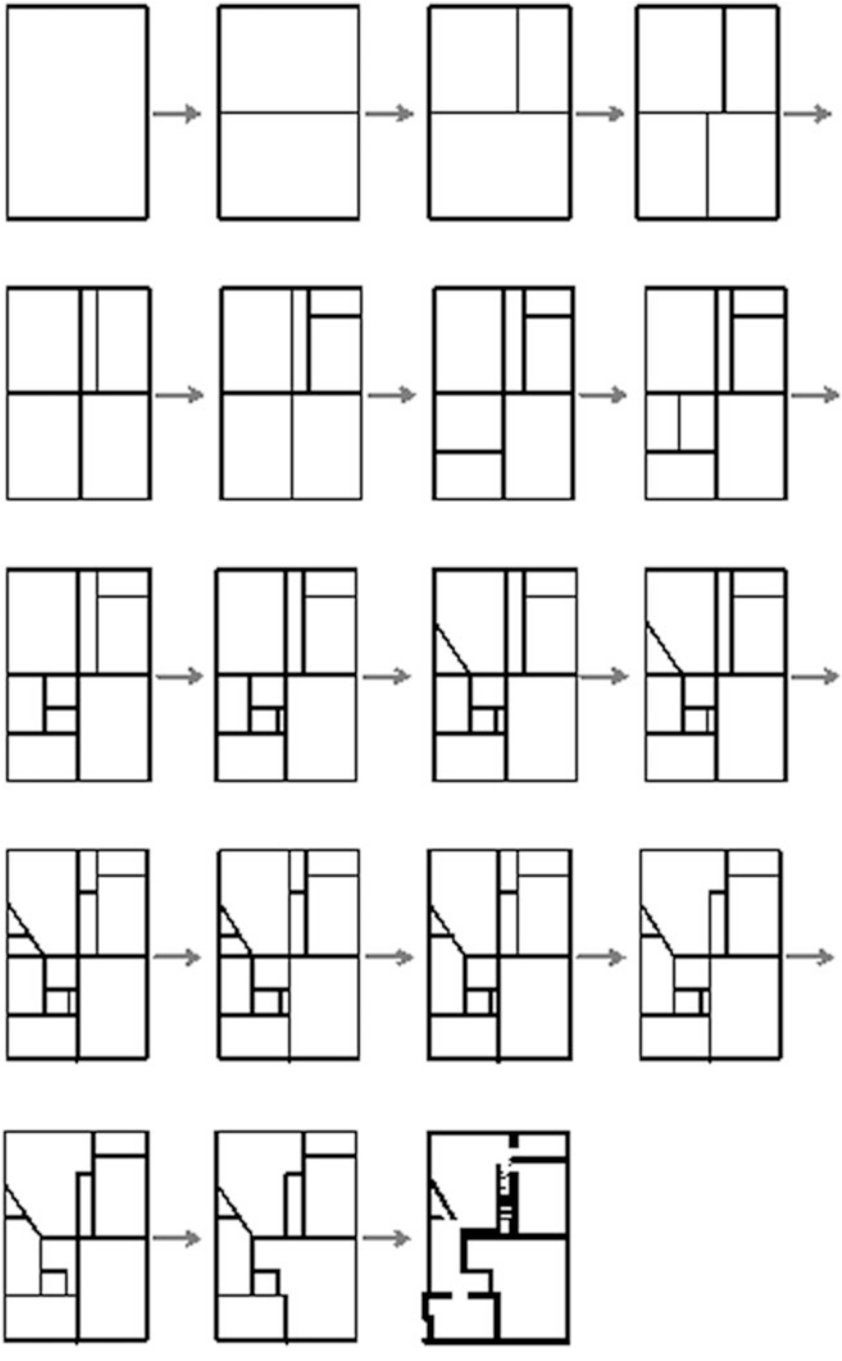


Fig. 4 Generic grammar derivation – Malagueira house Ab

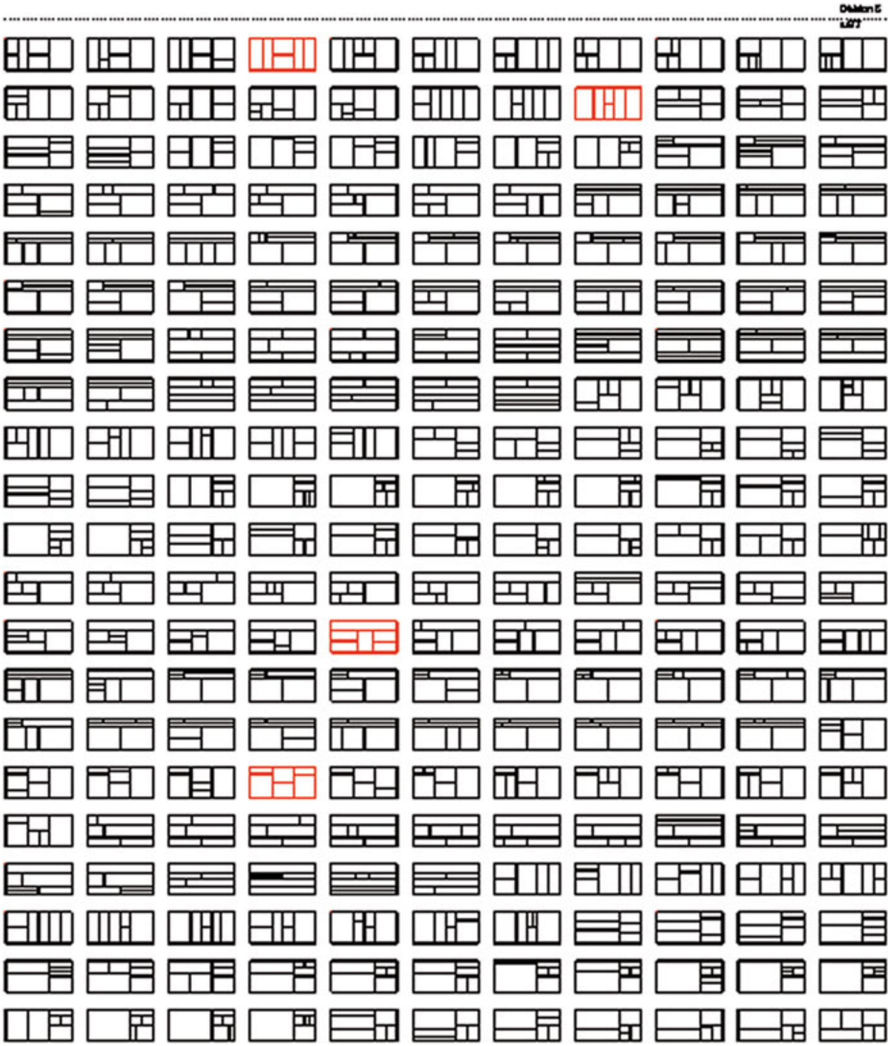


Fig. 5 Generic grammar corpus of solutions for five divisions (part 1)

configuration in a Palladian villa. In comparative terms, the derivation of the Malcontenta using this alternative method proves to be faster.

The Winslow house (Fig. 3) constitutes an appropriate case of prairie houses because is mainly self-contained. Contrary to most of the typical layouts of prairie houses where normally a crossed (or butterfly shaped) array is performed, Winslow could be underlined by a rectangular bounding shape. The inside layout could be easily described by a series of orthogonal axes very much alike a grid or matrix. This was also one of the first houses of the style used in this study as a case for derivation and possible conversion from additive grammar to subdivision. There are some resemblances shared with a Palladian typology: the rectangular outline, the grid like interior, the use of orthogonal elements, the emphasis on the social area of the house which occupies the core of the dwelling and extends itself through communicating rooms towards the outside creating progressive areas of privacy versus exposure, the careful and strategic addition of external elements that host entrance points and terraces occupying the main symmetry axis.

The derivation of Winslow can be summarized in 16 steps from start to completion. The first step is the boundary settlement, a bounding rectangular shape that already abstractly describes the final outcome. The second step uses a typical rule used in the Palladian alternative grammar. It is a rule to ensure the symmetry between the east and west wings. This subdivision rule proposes vertical divisions by placing two vertical cuts through the outline created. This divides the space into three areas, a central entertainment zone and two peripheral spaces east and west. This is the first draft for the social area. Steps 2–8 provide a series of divisions that allow further detailing of the space. In this Winslow house case spatial merging processes are especially useful for creating the distribution corridor. The last Step concludes the design process by adding some external areas of design. Very much like a Palladian villa, porticos are added to the main design for entrances, verandas and communicating terraces, with the entertainment zones creating transitional spaces between interior and exterior.

The derivation of Malagueira houses using the generic grammar involves an adaptation of the original Malagueira grammar rules [5] that served as a reference type for the conception of the generic grammar. The original grammar is a typical subdivision grammar and, as explained, is the driving force behind the design of this generic grammar.

The example in Fig. 4 illustrates a typical two-bedroom, two-storey, terraced, semi-detached house, type Ab under the classification system devised by Duarte. The proposed derivation uses the subdivision rules previously explained, plus particular shape rules that address Siza's spatial configuration. After the subdivision is performed, the steps that follow diverge from the original grammar and are closer to those tested in the previous derivations. Step 1 is the plot insertion, which involves applying a self-contained rectangular shape. In the case of the Malagueira houses the envelope shape is not parametric, but has a fixed size that reflects the available plot space with the same dimensions and area for each house. This is determined by the plot dimensions of 12×8 m, a perfect 3:2 proportional ratio and a resultant plot area of 96 m^2. Step 2 applies Rule 3 for horizontal subdivision, segregating interior from exterior space. At this stage the yard/exterior space is allocated. Step 3 applies the vertical division, creating a division between the interior functional areas. The house layout now begins with the allocation of (service versus living) zoning. Due to the true nature of this subdivision, recursive vertical and horizontal divisions are performed to carry out the zoning and spacing. These rules are no more than parameterizations of the division rules exemplified. In comparison with the other grammars where only vertical and horizontal divisions are performed, Malagueira houses allow for diagonal divisions as showcased in this house type.

Generic Grammar Validation

Figures 5 and 6 represent the corpus of solutions generated from recursive subdivisions of the outline with up to five subdivisions. The result is an extended corpus of 477 possible solutions for 5 divisions. This makes a total of 569 solutions if the generation process only applies the division rules 5 times. Experience has shown that the generation of Palladian villas, Malagueira and particularly Prairie houses take several recursions to be successful. As previously seen Malagueira house Ab allows for 16 division steps (Fig. 4) and Winslow Prairie house allows 16 steps (Fig. 3).

Fig. 6 Generic grammar corpus of solutions for five divisions (continued part 2)

This only shows the potential of a generic grammar of this sort using subdivision as its generative tool. A great deal of designs can be generated as shown in Figs. 5 and 6 and the feasible generation of pre-existing solutions shown in the partial tree diagram with the delineation of possible divisions. This grammar can potentially generate any solution that is self-contained in a rectangular outline. Figure 5 and 6 show the possible patterns allowed by the Palladian villas and the Malagueira. These are incorporated into the shape rules parameterization as shown in the shape rules sequence demonstrated in table 8.1. These patterns allow for underlined grids of 3×2, 3×3, 3×4, 5×5, 5×3, 5×4, 5×5. Despite the abstract grid principle, this is only a rationalization used to maintain the proportion ratio of the divisions because in practice only the desired divisions are performed. Malagueira allows for eight basic layouts that derive from vertical and horizontal divisions. This way the basic layout is determined in three divisions.

There are 477 possible solutions for the corpus of 5 divisions, combining vertical and horizontal. The solutions in red represent potential Palladian villas solutions, green Prairie houses and blue Malagueira. This corpus only focus on configuration, the shapes and proportions vary parametrically. The bottom red example resembles in configuration the Palladian villa Ragona and the immediate above resembles villa Angarano designed and built by Andrea Palladio with underlining 3×3 grids.

There are 477 possible solutions for the corpus of 5 divisions, combining vertical and horizontal. The solutions in red represent potential Palladian villas solutions, green Prairie houses and blue Malagueira. This corpus only focus on configuration, the shapes and proportions vary parametrically. The bottom red example resembles in configuration the Palladian Godi designed and built by Andrea Palladio with underlining 5×2 grid. Additionally are blue examples which fit Malagueira criteria and good starting points for houses Ab and Bb.

This corpus only focus on configuration; the shapes and proportions vary parametrically. The diagram represented replicates the possible sub-divisions that occur using the subdivision grammar by mapping the horizontal and vertical divisions. The solutions in red represent potential Palladian villas solutions, green Prairie houses and blue Malagueira.

The range of potential solutions illustrated for five divisions illustrate, among others, examples of the original corpus of Palladian villas Prairie and Malagueira houses. Among the pre-existing corpus of solutions can be found the Palladian villa Godi designed and built by Andrea Palladio with underlining 5×2 grid, and examples which fit Malagueira criteria for houses Ab and Bb.

Conclusion

Previous shape grammar work has tended to propose a unique grammar that describes a particular corpus of designs or, for that matter, an alternative grammar for a grammar already developed, even though the range of work produced by the grammar also has intrinsically common features. This implies that finding and studying this grammar tells us something about the essence of the corpus of work.

The present work refutes a common assumption of this approach, namely the uniqueness of the design style that one grammar can produce. Given that there is more than one way to reproduce designs, more than one suitable grammar and that one grammar that can produce more than one style, many different representations are potentially viable. Shape grammars can thus potentially be manipulated to generate a larger corpus of new designs. This may allow for efficiency in exploring shapes and analysing results, thus widening the scope of grammars. The advantages and limitations of shape grammars can be considered in two domains: advances for the research field and advances useful for architectural practice. The generation of shape grammars is useful in practice primarily for their potential in exploring potential design options. This could be used as a way to tackle diversity in mass customization as demonstrated in various works. In addition shape grammars have proved successful in industrial design such as in the car industry by Cagan and Osborn. For research shape grammars are important testimonials and tools that concentrate know how and architectural 'best practice'. For art historians these could be useful tools in the identification and classification of non-assigned authorship of buildings.

If shape grammars with specific languages can recreate (or replicate) design solutions within a specific family of solutions, a generic grammar can offer a range of design solutions and several families of results. This could be finely tuned to allow for a design consistency using parameterization as shown in previous sections of this work. A generic grammar such the one exposed allows for an additional level of flexibility to the current shape grammar without losing coherence. This derives from one of four rule types: addition, subtraction, subdivision and concatenation. Fine tuning can be achieved by the restrictions and conditions provided. Applications of this could be easily tested in practice where the designer would only require the adjustment of the parameterization as best suited. Variables such as the plot size, or the area available for each room or rooms could be predetermined. It is important to note that in the generic grammar only the fourth stage has a common branch. From there ramifications confer upon each design family its signature details. Such details can also be customized. The three original case studies and their parameterization are merely indicative and are presented to illustrate and describe the grammar. Others can be added. An obvious limitation to the rules as demonstrated is the geometry allowed. Due to the case studies selected, most of the designs propose an orthogonal setting and rectangular enclosure. This does not have to be a condition for other generic grammars but efficiently described the corpus that was selected. Other variables can be integrated to allow for other geometries by increasing the number of parameters used.

In addition, due to the two-dimensional nature of the majority of the grammars used the generic formulation was also represented two-dimensionally, but this could be easily converted into a three-dimensional formulation through a more extensive survey of the corpus of original solutions. Future work will focus on automatic inference of housing grammars by using the generic grammar as a base.

The original grammarians have extracted their rule set through observation, identification of common design patterns and analysis of the many solutions, but what is not clear is the rule inference process, as this is empirical, creative, and has not been to this point successfully explained. The generic grammar derived from a set of three languages in this paper leads to several observations:

A grammar can generate more than one language. The set of shape rules are not only a combination of the original rules but an optimization of the of the design intent. The careful synthesis of these shape rules can generate not only the original languages but other corpuses of solutions. It is thought that the generic grammar will serve as a foundation from which specific housing grammars can be described not as rule sets, but as parameter ranges. Future work will focus on the effectiveness and implementation of the generic grammar, with a focus on the meaning of the regions of design space between existing corpora. It is expected that the mutation of these design styles or the overlapping of rules will produce new consistent designs with a new hybrid style. Moreover, computerised implementation will represent a positive development, allowing for the exploration of design solutions and even the enumeration of design corpus results. The potential of this generic grammar will be fully tested with a computerised tool, as was the case with previous work developed for housing shape grammars, such as the ABC system and the Haiti gingerbread house grammar [3].

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