A Grammar of Perforated Masonry Walls

A formal analysis of brick walls used for shading and ventilation in Paraguay

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Abstract

This paper describes a grammar for Perforated Masonry Walls of contemporary Paraguayan brick architecture. In these walls, bricks are arranged to generate different patterns, utilizing a series of rules that define the formal relation between oblongs. The masonry walls selected for this study provide shade and natural ventilation, and are used to improve thermal comfort in buildings. The paper, first, presents an analytical study that extracts the underlying generative rules for pattern-making of these masonry walls illustrating the construction logic of the walls. Then, a generative exploration that demonstrates the possible uses of the developed grammar is shown.

Keywords: Shape grammars; Design rules; Shading Strategies.

Introduction

Perforated brick walls that operate as shading elements constitute a passive design strategy for cooling buildings and improving thermal comfort conditions. Perforated masonry walls built with different block units and patterns commonly appear in built works in Latin America as a regional solution to achieve thermal comfort. A wide range of contemporary examples can be found across the continent, including Raul Villanueva's covered plaza at the *Universidad Central de Venezuela* (1944–1970), and Eladio Dieste's masonry panels at the Atlántida's church (1953). These examples of regional architecture create a language of locally grounded designs. Paraguayan architects have also produced a series of shading walls using brick as the basic construction unit. The works of Javier Corvalan, Jose Cubilla and the studio of Francisco Tomboly and Sonia Carísimo can be exemplified for their innovative uses of brick in perforated masonry walls.

This study aims to contribute to the design of passive cooling strategies for buildings, intricately based on the climatic conditions on which they stand. The paper is part of an ongoing research that aims to optimize the thermal performance of perforated brick walls. One of the goals of this study is to generate a comprehensive language for the design and construction of affordable shading systems in subtropical climates. This responds to the recognition of the increasing need to incorporate passive design strategies into local design and building traditions. Perforated masonry walls, in this sense, are an important part of an architecture of heterogeneous space (Hensel, 2008), one which is formed by layers of filters and microclimates, as opposed to the enclosed and hermetic building.

At the same time, the study presents an analytical approach that aims to extract the generative rules of design of the selected perforated brick walls and seeks to create a grammar to guide the design of perforated masonry walls. While the case studies in this paper exemplify works of different Paraguayan designers, the intention is not to present a complete and extensive list of all the buildings that utilize filter walls. Rather, the focus is on presenting the similarities and differences of the selected case studies through a formal analysis.

Previous studies have suggested the adequacy of perforated brick walls for achieving thermal comfort and concluded that these walls act as an efficient protective skin for buildings (Zárate, 2015). Also, results generated for the purpose of this study by *Climate Consultant* (Version 6.0, Build 10), a software which provides designers with guidelines of the most efficient passive cooling or heating strategies according to a defined location, support that sun shading windows and natural ventilation are one of the most efficient design strategies to achieve thermal comfort in Asuncion, Paraguay. Consequently, perforated brick walls render appropriate for the existing environmental conditions of Paraguay, providing a functional and aesthetically defined solution.

Figure 1: San Francisco Building, by architect Jose Cubilla. Photo Credits: Lauro Rocha

Perforated Masonry Walls

Perforated masonry walls form part of the language of contemporary Paraguayan Architecture. An emerging group of designers in Paraguay has been reinventing the local traditional brick architecture in creative and clever ways (Biagi, 2017). Brick filter walls correspond this architecture that has produced a series of innovative buildings, where these walls have an important role in the articulation of the spaces and the definition of the facades.

The perforated walls selected for this study share some similarities. This research focuses specifically on case studies built in the last fifteen years in Paraguay that make use of standard brick units and different construction patterns to generate perforations in the walls. Also, most of the case studies selected are from the capital city Asuncion, and its surrounding metropolitan area. Lastly, they are mainly self-standing walls.

Within larger building, the studied perforated brick walls are mostly located in semi-closed areas: i.e. corridors, patios, and semi-covered living rooms. The perforated walls from the selected buildings serve a twofold aim: they are used to filter sunlight and, at the same time, they allow for natural ventilation in these intermediate spaces.

In addition, the selected case studies share some properties regarding their construction logic. They predominantly use standard brick units to generate different patterns with varying levels of porosity, resulting in unique aesthetic solutions. They differentiate from prefabricated perforated blocks in that they utilize standard bricks typically used for the construction of the rest of the walls of the building.

Perforated masonry walls can be classified according to the material and type of block used. Concrete and clay bricks are most typically used, in the form of prefabricated blocks of different characteristics. While some of them are standard rectangular prisms, others already contain perforations within the block. The examples analyzed in this study utilize mainly ceramic rectangular prisms without perforations, and the construction rules are the ones that allow the generation of the voids in the wall.

The use of bricks to create perforated walls rather than using pre-fabricated perforated blocks might be related to the local industrial conditions. The less developed industrial base and the widely available low-cost labor prompted designers of the region to focus their work on traditional construction materials, namely, brick and mortar (Kostrencic, 2015). Consequently, the inherently low-tech tradition of brick masonry has been revived by architects to create innovative works using this construction technique, creating an architecture with a local character. The resulting architecture maximizes the use of brick, and perforated masonry walls are one of the elements of this design approach.

The Grammar

The chosen analytic tool for this study is shape grammars. A shape grammar allows designs to be expressed in a set of rules that explain the genesis of form (Stiny, 1980). The rules obtained from the grammar are easy to transmit and to utilize in the generation of new designs, thus constituting a powerful tool for the exploration and the creation of a design language. Understanding design as a form of "calculating" (Stiny, 2006) constitutes the basis of this analytical and generative method.

Shape grammars have been extensively used in both the analysis and generation of designs. As an analytical tool it has been used in studies of different scales, from urban forms (José Pinto Duarte, Rocha, & Ducla Soares, 2007), to housing typologies (José Pinto Duarte, 2005). Among the wide array of studies that make use of shape grammars, the studies where shape grammars are used to formally describe the generation of patterns, i.e. Islamic patterns (Jowers, Prats, Eissa, & Lee, 2010) and window designs of Frank Lloyd Wright (Rollo, 1995), constitute a precursor for this study. These studies indicate the potential of shape grammars as a tool to analyze pre-existing pattern designs.

Shape grammars have also been used to depict the construction logic of vernacular building systems. Previous studies have demonstrated its ability to describe a generative language of aesthetically rich architectural solutions for low-tech construction methods (Knight, Sass, Griffith, & Kamath, 2008). The perforated masonry walls analyzed in this study have a low-tech construction logic that utilizes a single element, the brick, in the creation of perforated walls. The richness of the design of perforated walls seems to rely in the disposition of the elements and the design rules that generate complex patterns. This suggests the adequacy of using Shape Grammar in the analysis of these filter walls.

This study presents an analytical and generative grammar of perforated masonry walls. First, the analytical grammar conveys the building logic and its construction coherence and, at the same time, describes the generation of a diversity of patterns with distinct aesthetic solutions. Then, the generative part explores the use of the grammar in the creation of new designs based on the extracted rules.

Extracting the Underlying Rules of Design

The grammar is based on the existing construction rationale of traditional bricklaying techniques, building upwards, row to row. Figure 2 presents two versions of the same rule for layering bricks, both accurately describing the spatial relation between two adjacent bricks. However, only Figure 2-A represents the correct construction logic of placing one brick on the top of another placed previously. The grammar developed in this study follows the same principle.

The grammar developed in this study follows the approach presented by Stiny in the Kindergarten grammars (Stiny, 1980). The three-dimensional grammar proposed by Stiny uses labelled oblongs and a set of rules to generate languages

of designs. Similarly, this study uses three dimensional shapes, labels and defined spatial transformations to analyze the different case studies.
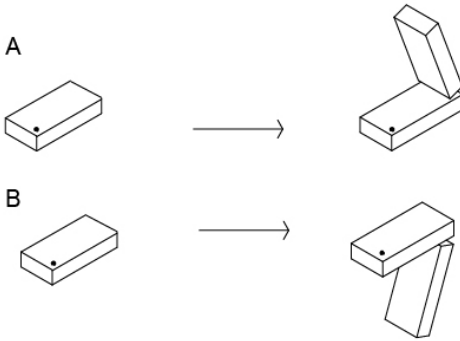

Figure 2: Constructive logic of the grammar.

The study develops the grammar in a three-dimensional representation rather than a two-dimensional study to be able to accurately describe the constructive logic. This derives from a conclusion of an initial exploration in two dimensions that could not accurately convey the construction rationale of the perorated brick walls. The selected case studies also have depth and textures that could not be transmitted in a planar representation of the grammar.

There are certain bricklaying rules that seem to be common to most brick walls, which are presented in Figure 3. These rules appear repeated through the different case studies also in the generation of perforated walls. Rule A allows to generate a row of variable length and rule B allows to construct upwards.

The developed grammar allows one to identify the set of rules of design for each case study. The grammar establishes that each case study utilizes a set of combined rules to generate different patterns. The analytic grammar also allows to identify that most of the case studies utilize Rule A and Rule B, to generate rows of bricks and to move upwards in the construction.
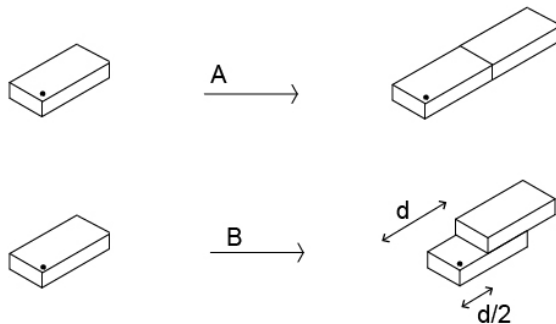
Figure 3: Bricklaying rules.

The grammar shown in Figure 4 does not show all the rules needed to generate the walls in each case due to space limitation. Rather, it depicts the most important rules that allow to generate voids in the design of the wall. Also, Figure 4 does not illustrate the computation to generate each case but rather focuses on showing the extracted main rules that synthesizes the perforated masonry wall.

The grammar includes labels in the definition of the set of rules of each case study. Labels are used in shape grammars to gain control over the symmetry of the forms in the implementation of the rules (Stiny, 1980). Labels constrain the implementation of rules and permits to accurately describe the construction logic of the designs. An example of the implementation of labels in the analysis can be seen in Figure 4, case study number 1, "Casa tres cuartos". This example shows a set of two rules that differ according to the location of the label.

The simplicity of the rules becomes evident in the overall design of the walls. Rule R2, from the "San Francisco" building is particularly interesting in this manner, because it allows one to generate large voids in the form of square patterns. Another instance of a simple rule generating complex forms can be seen in the first example in Figure 4, "Casa tres cuartos", where triangular shapes characterize the design solution.

Another interesting finding is that rules are repeated across different case studies. For instance, Rule R4 appears in several examples analyzed as an easy way of generating void between the blocks. This rule appears in both examples "Vivienda Lui" and "Casa Ilona", described in Figure 4.

The analytical grammar allows one to discover the potential of certain rules to form spatial configurations. An example of this is Rule R9, shown in Figure 5, which permits the wall to acquire a more spatial nature, away from the planar-based form of a common wall. The implementation of this rule and its variation could be useful in the exploration of the structural aspects of the filter walls, by generating walls that could be self-supported.

The grammar also allows one to describe the constructive logic of the wall by defining the relationship among parts and depicting how the wall is built. The representative nature of the grammar portrays the construction logic embedded in the spatial relationship between the blocks.

Generative Grammar: Designing with the rules

After developing the grammar following the approach just described, the study tested the use of the grammar as a generative tool. The second part consisted of implementing the design language to explore the possibilities of the system to be used as a design tool in the creation of new perforated masonry walls.
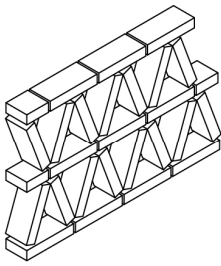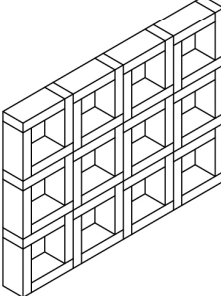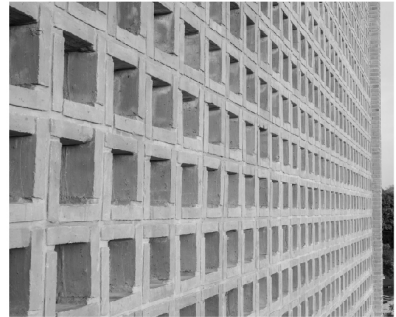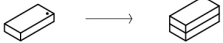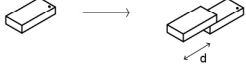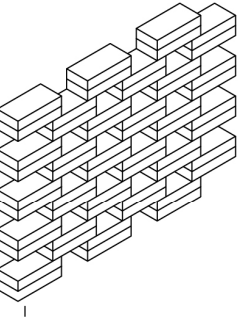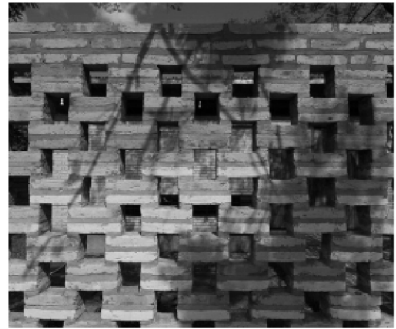
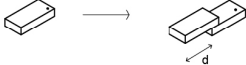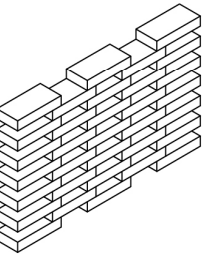| Building	Rules	Design solution	
1 "Casa tres cuartos" Designer: Carlos Zarate Year: 2015 Location: Asuncion, Paraguay Photo Credit: Leonardo Mendez	R1 a R1 b		
2 "San Francisco" Designer: Jose Cubilla Year: 2013 Location: Asuncion, Paraguay Photo Credit: Lauro Rocha	R2		
3 "Vivienda Lui" Designer: Oficina Comunitaria de Arquitectura. Year: 2016 Location: Mariano Roque Alonso, Paraguay Photo Credit: Federico Cairoli	R3 R4		
4 "Casa Ilona" Designer: Culata Jovai Year: 2013 Location: Asuncion, Paraguay Photo Credit: Federico Cairoli	R4		

Figure 4: Analytic grammar
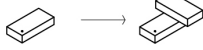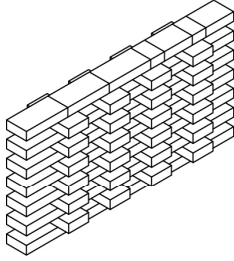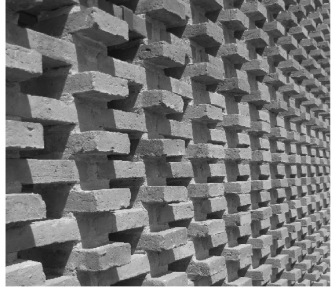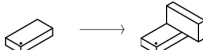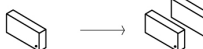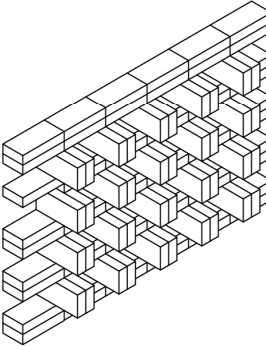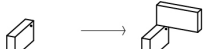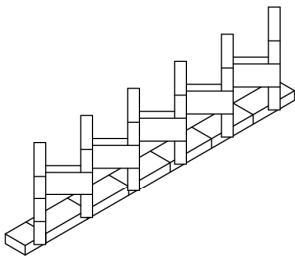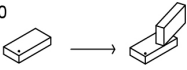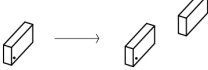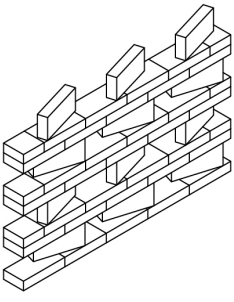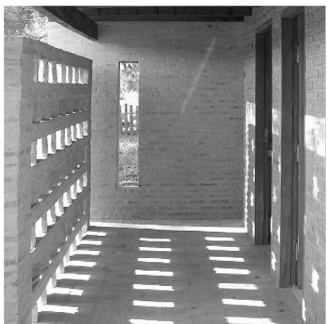
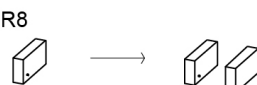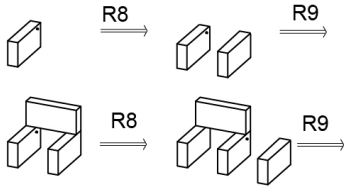| Building	Rules	Design solution	
5 "Vivienda Ubaldo" Designer: -=+x- Year: 2010 Location: Asuncion, Paraguay Photo Credit: -=+x-	R6		
6 "Estudio Notarial" Designer: Sonia Carisimo Year: 2010 Location: Asuncion, Paraguay Photo Credit: Sonia Carisimo	R7 R3 R8		
7 "Oficinas Guarani" Designer: Cristaldo, Silvero, Diarte Year: 2013 Location: Itaugua, Paraguay Photo Credit: Berenice Gomez Crosa	R9		
8 "Clinica Médica" Designer: Estudio Elgue Year: 2006 Location: Villa Oliva, Paraguay Photo Credit: Estudio Elgue	R10 R11		

Figure 5: Analytic grammar
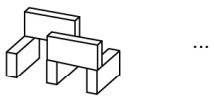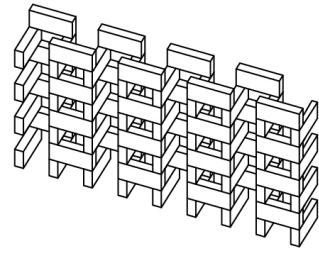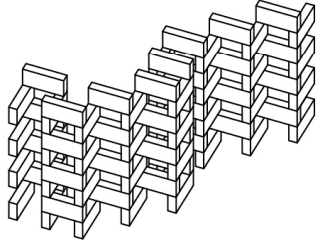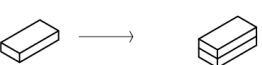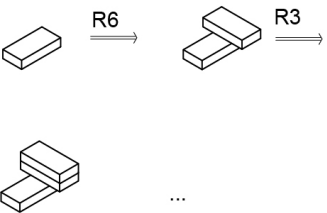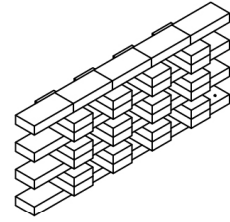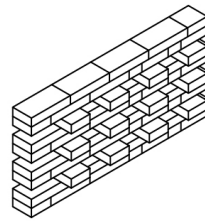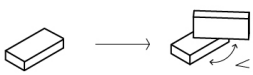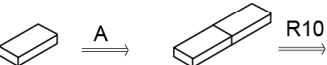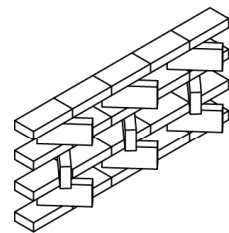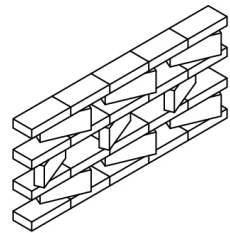
Rules	Rule aplication	Design Variations
Case A (1): Rule Combination		V1
Case A(2): Rule combination		V1
Case B: Rules with parametric variation		V1

Figure 6: Generative grammar

The generative grammar presents two distinct explorations, shown in Figure 6. The first iteration (Case A) explores the combination of different rules in generating unique designs. Two variations, Case A (1) and Case A (2) are presented following this logic. Then, the second iteration (Case B) examines the opportunities for parametric variation within the constraints of a fixed rule.

The first exploration (Case A) shows walls generated by the combination of rules from different case studies. Case A (1) combines Rule R8 and Rule R9 in the creation of two distinct designs. The rules are obtained from case studies "Estudio Notarial" and "Oficinas Guarani" (Figure 5), respectively. The second variation, Case A (2), based on rule combination utilizes Rule R3 and Rule R6, which are derived from case study "Vivienda Lui" (Figure 4) and "Vivienda Ubaldo" (Figure 5). The variations obtained are two walls with different percentage of voids.

The use of the grammar as a generative tool in this iteration shows the potential of combining rules that are compatible in terms of construction logic. The exploration based on rule combination also allowed one to test the use of the rules in the generation of walls that have an increased spatial expression. Rule R9 is used to generate two walls shown in Figure 6, which either break the linear form of the wall or are thicker than the width of the brick unit used. This kind of exploration could allow designers to generate screens that define spaces or walls that have an increased overall width.

Case B shows the potential to explore parametric variations within a rule. The parameter that is being altered in the presented Rule R10, extracted from case study "Clinica Medica" (Figure 5), is the angle of rotation of the brick. The two designed walls only differ in the rotation angle, but this is enough for them to acquire a different texture, which could become more evident by the shade cast by the wall on itself. The parametric variation within the grammar appears to be a playful design resource that can add texture and increasing the richness of the design of the perforated wall.

Rule R10 is not the only extracted rule that allows for parametric variations. Rule R4, among other ones presented in Figure 4, could allow variation in the distance between blocks, creating walls with gaps of different sizes. By adjusting this distance between the blocks, one can obtain a denser result than the original case study.

Conclusion

This paper presents the first step of a research aimed at developing a system to purposefully design perforated masonry walls for a given setting, thereby optimizing the performance of perforated masonry walls. The performance refers to the ability of brick filter walls to improve thermal comfort in buildings, by providing shading and natural ventilation. A second stage of this research will utilize the obtained grammar and apply simulation and optimization tools in a digital framework to find an optimized design solution within the constraints set by the defined grammar.

The next step of this research will study the performance of the walls based on the extracted grammar rules, and use the grammar to generate optimized design solutions. With this goal in mind, this paper presented the development of an analytic grammar of the walls and tested the use of the grammar as a design tool in the generation of new designs.

The different patterns and brick arrangements of the case studies where analyzed using Shape Grammars. This methodology was successful in extracting the series of rules that synthesize the design of the examples analyzed. The walls that were studied make use of a set of rules based on the construction logic of traditional masonry practices.

The transition from the analytical grammar to the generative grammar shows the possibility of using a shape grammar both as an analytic and a generative tool. The generative grammar revealed that the rules might be applied to create walls with less or more void area. The grammar allows one to develop a variety of walls with control on the overall geometry, making it possible to provide several aesthetic solutions.

The generative part of this study presents two distinct explorations based on the previously developed analytic grammar. The exploration describing parametric variations within a set rule reveals how the permeability of the walls could be adjusted according to the value of one parameter, the rotation of the bricks. This suggests that the grammar, as a design tool, could allow architects to have an increased control in the definition of selected parameters of the design. These parameters can be either conditioned by aesthetic aspirations or be defined by the functionality of the walls, or both.

At the same time, the grammar that incorporates parametric variation presents the opportunity to focus on the performance of the perforated walls. Parametric variations could be generated after each rule set to control the performance of the wall, by changing the size and number of openings, thereby affecting the shade casted by the wall and the ventilation rate. The next step of this research will establish parametric variations within the set grammar rules to allow adjustments in indicators related to performance, working towards a digital framework that allows architects to design optimized solutions.

The focus on passive design elements that use widely spread and locally abundant construction materials also allows re-imagining low cost and affordable ways of designing buildings, with the help of generative design methodologies. The presented grammar could be a way to both synthesize a design language and transmit culturally sensitive architecture practices.

Finally, the results of this study suggest that architects and designers could enhance the design process of perforated masonry brick walls by using the grammar. This design language would only be complete when using the grammar within a specific context with all the complexities that a design problem presents. This study does not intend to oversimplify the intricacies of designing and building but rather wishes to add a tool to the challenging process of constructing locally grounded solutions.

Acknowledgments

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