Santa Marta Urban Grammar

Towards an understanding of the genesis of form

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The research presented here aims to understand how spontaneous occupation in informal settlements evolves, how to develop guidelines for the requalification of these settlements, and how to plan new settlements in similar conditions. This paper focuses on the use of a parametric urban grammar as a methodology to describe the complex urban form of informal settlements, explaining how buildings and pathways create the maze-like urban structure, how different building typologies are located according to internal and external forces like topography, and urban context and functional organization of these buildings.

Keywords: Santa Marta, informal settlement, shape grammar, urban grammar

INTRODUCTION

Informal settlements are present all around the world and it is estimated that nearly one billion people are living in such settlements, (United National Human Settlements Program, 2015) characterized by spontaneous urban occupations as a result of fast urban growth (Davis, 2006) and lack of resources. Although the relative number of people living in informal settlements decreased between 1990 and 2010, the absolute number during the same period increased from 650 to 800 million. Addressing how to improve the living conditions of these people is an important Millennium goal set by the United Nations to be reached by 2020. (United National Human Settlements Program, 2015) Informal settlements have problems related to poor housing quality, overcrowding, inadequate access to safe water, inadequate access to sanitation and other infrastructure and insecure residential status (United National Human Settlements Program, 2015) but they are a fast and economic answer for the lack of housing.

The goal of the research is to understand how informal settlements occupy the urban space, spontaneously evolving over the territory, define guidelines and a methodology to requalify informal settlements and plan new settlement in similar conditions. As a prior step to define a general methodology applicable to all informal settlements, the study focuses on a specific case study located in the south area of Rio de Janeiro and called Santa Marta, which evolved over a steep topography and near a prime area of the city.

The research encompasses the following five stages: (1) Creating a digital model of the case study based on a photo site survey (Verniz et al, 2016); (2) Creating a virtual model that allows remote access to the case study; (3) Creating a computational model that explains the existing urban occupation (analytical grammar); (4) Development of a shape grammar to requalify the case study (requalifying grammar); (5) Development of a shape grammar to design new settlements on sites with similar spatial properties (design grammar).
The work described in this paper focuses on the development of the analytical grammar with the aim to explain how the maze-like structure of Santa Marta evolved, creating a complex urban morphology out of buildings and pathways.

STATE OF ART
Santa Marta is located on Dona Marta hill and it can be considered an example of how informal settlements coexist with formal cities in Brazil, providing the workforce with housing near the workplace. The hill’s occupation started in 1924 when a priest built some houses to shelter workers from the construction site of Santo Ignacio’s High School. The place grew fast after the American Great Depression in 1929, which affected the Brazilian coffee economy and induced an intense urban exodus. Many farm workers then migrated to the city, becoming security guards, factory workers and housekeepers. (Meirelles and Athayde, 2014).

This research is based on previous work on the development of housing and urban grammars that addressed the problem of creating a grid to generate housing layouts and urban plans following grammar rules (Stiny and Mitchel, 1978; Andrew Li, 2001; Beirão and Duarte, 2005). As informal settlements are not planned, the agglomeration of building into a grid is not easily identifiable, although it does exist. As such, we considered that a bottom up approach would deliver a better result.

Duarte et al., (2007) presented an urban grammar for the Marrakesh Medina, an ancient fabric that grew spontaneously over time, resulting in a complex urban form that express social conventions and physical conditions. Subsequently, Barros et al. (2013) described the structure of Mozambican slums and Dias (2014) explained how buildings expanded over the time in Rocinha, the biggest Brazilian slum. The steep topography of Santa Marta makes it a unique and innovative case. Figure 1 shows the Santa Marta’s plan and indicates the three entrances, where the informal settlement communicates with the formal city.

METHODOLOGY
The methodology used to infer the analytical grammar was divided into three steps. The first step was the identification and classification of the different polygonal shapes that represented the buildings. This work was based on a map of Santa Marta provided by the municipality, complemented by the results of the photo survey. The second step was the analysis of the urban topology, identifying building clusters and pathways between them and inferring the rules to locate buildings. The third step was to find the relation between the shape of the buildings and external and internal forces, understanding the factors behind the complexity of such shapes. In this last step, it was inferred rules to distort basic quadrilateral building shapes and the sequence in which the grammar rules should be applied.

In the first step, buildings were separated according to use into two groups. The first group included housing and commerce and the second one, temples, planned social housing, public squares and sport fields. The first group represents the informal building production and it was used to develop the grammar. It included 1011 buildings, which were further classified according to n, the number of sides in their polygonal shapes with $4 \leq n \leq 11$, and the type of shape, convex or concave.

In the second step, urban topology was identified and seven rules were inferred. They define the location of a new building, considering a previous one as a reference.

In the third step, the urban structure and the building configuration were analyzed to understand the internal and external forces that influenced the building shapes. The maze-like formal structure of Santa Marta is a result of these forces:

- Topography, which is an important feature in the majority of informal settlements in Rio de Janeiro. The rough terrain in the region works as a barrier to the growth of the formal city, which tends to occupy flat or slightly sloped surfaces, preferable for construction than steep ones, leaving these areas empty for
Figure 1
Santa Marta's chart.
Figure 2
Decision-making flow chart.

1. Adds a quadrilateral shaped building
2. What is the topological relation with the urban context?
3. Applies the rule that corresponds to the decision (R1 to R7)
4. Will the new building be located at the formal limit of the slum?
5. Aligns the new building with the average contour line
6. N
7. Are there any pre-existent buildings which the new building could share walls or have any spatial conflict?
8. Applies the rule to reshape the building according to the urban context (R8)
9. Y
10. Are there any changes from inside the house (functional organization)?
11. Y
12. Applies the rule to reshape the building according to functional changes (R8)
13. N
14. Finished design
occupation by the informal city. Although informal buildings are not planned, they tend to follow the topographic contour.

- Urban context, as the placement of buildings is influenced by existing buildings, formal and informal, as they constrain accessibility, the ease of construction, and the perception of safety.
- Functional organization, as it constrains how buildings are shaped and sized.

These forces are the reason why buildings in Santa Marta have a potentially complex polygonal shape. In addition, the complex network of pedestrian pathways is not planned but a result of circulation needs. On the east side of the settlement there is a cable train that provides for public transportation to the upper parts of the hill, but this was introduced much later and has not influenced the existing urban morphology.

The growth of informal settlements is spontaneous and the goal is for buildings to occupy all the available space, taking into account the scarcity of resources and security issues. (Alexander, 1973, David Gouverneur, 2015) Santa Marta’s building aggregation was analyzed and rules were inferred to explain its emergence and growth. Our work followed a bottom-up approach similar to the work on the Marrakesh Medina (Duarte et al, 2007) where buildings and circulation emerge as a result of the process to occupy available space. However, while in the Marrakesh grammar circulation is defined first and buildings are placed afterwards, the Santa Marta grammar works the other way around, with buildings defining sinuous pathways.

Santa Marta has a specific urban configuration that is delimited on the South by the formal city, on north by the top of the hill, on east by a private property, and on west by a national park. This characteristic creates a dense, steep and confined urban space. To solve the complex configuration of Santa Marta, Figure 2 shows the decision-making flow to define the order in which contextual forces should be taken into account. The first, Topological context indicates the way buildings inside the informal city relate to each other, in terms of location and circulation between them. Topographic context indicates the way that buildings inside the informal city relate to the terrain. Urban context indicates the way buildings inside the informal city are shaped based on what is already built in the formal or informal city. Topological context expresses the way a building’s internal functional logic influences its shape.

Topographic and urban contexts are the main forces and the order in which each is applied depends on the location of the building. As Santa Marta has well defined bounds the urban context predefines the alignment of buildings that are closer to its limits. As occupation expands, moving away from the limits, topography becomes more influential in the alignment of buildings. As buildings are not predesigned, in the process of locating, it is first assumed that they have a quadrilateral shape and then, functional organization plays its roles, giving the building its final shape.

**Urban Grammar**

The initial shape is a polyline representing the side borders of an existing street. Existing buildings represent the limits of the formal city and are placed on each side of the street, represented by polygons. Topography is depicted by contour lines, represented by gray polylines.

The vocabulary of shapes includes: the initial shape; quadrilateral polygons representing buildings; dashed lines that represent the circulation midline (streets or pathways); and circular labels that emphasize the nodes of building polygons.

Figure 3 shows the set of rules proposed for locating buildings. The Santa Marta urban grammar encompasses eight parametric rules. The first seven of these rules define the location of a new building. Each rule addresses a different urban topology and in all the building is as a quadrilateral polygon. The eighth rule adds sides to the initial quadrilateral polygon and at this point the building being located has its basic shape defined.
Figure 3

The set of rules for locating and modifying houses.
Figure 4
Generation of a six-sided polygon from a quadrilateral by recursive application of Rule 8.

Figure 5
The partial derivation of the south-west entrance of Santa Marta.
Figure 4 illustrates how a six-sided polygon can be generated following the application of Rule 8. To generate a n-side polygon, Rule 8 should be applied n-4 times. The growth of the informal city starts close to the formal city, utilizing resources that are already available, such as existing access pathways and walls, minimizing the use of resources, particularly space and materials, thereby generating a very dense urban fabric. The growth of Santa Marta started from three different places, all located at the border of the formal city where three streets end and from where it is possible to access the place: two at the bottom and another at the top (Figure 1). Figure 5 shows the growth of zone of Santa Marta from its Southwest entrance by recursive application of shape grammars rules (Figure 3).

CONCLUSION
This work presents the preliminary version of a shape grammar to describe the complex urban form of informal settlements in steep locations, using a particular settlement in Rio as a case study. So far, we have inferred rules to explain the buildings’ locating and shaping processes. Key to the definition of the grammar was identifying the topological relations between buildings and pathways, and between adjacent buildings, as well as recognizing the influence that factors like topography, urban context, and functional organization have on site occupation. Proposing an adequate decision-making flow was an important step to explain the existing complex urban form as a result of the interplay between such factors, which are depend the specific location of the buildings. The option to use a parametric quadrilateral polygon representing buildings, that is positioned and then shaped was crucial to avoid the need for a set of rules for each n-sided polygonal building. Future steps in the development of the grammars are concerned with the inferring of new rules to explain the generation of other public spaces, such as squares and stairways.

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