A Generative System for the Terrain Vague

Transcarioca Bus Expressway in Rio de Janeiro

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The transport infrastructures are important elements in the cities, but, as there is a lack of planning, they tear through the urban fabric and leave empty spaces. Due to government and private disinterest, these spaces become vacant, forgotten and degraded. However, these extensive Terrain Vague offer new potential for urban use. To exploit this potential, we need methodologies that can offer personalised, extensive, feasible urban solutions. For this, we propose a computational generative system, following a 4-step methodology: 1) Site analyses and Terrain Vague identification; 2) Site classification according to parameters based on a ``visual grammar''; 3) Algorithm associating space properties with geometric transformation to generate solutions: namely transformative operations in public spaces, additive transformations in semi-public spaces and subtractive operations in semi-private spaces; 4) Solution evaluation and development, according to shade criteria, spatial hierarchy and volumetric density. With our own algorithms combined with genetic algorithms, we guided the evolution of 50 volumetric solutions. The exponential increase in information requires new methodologies (Schwab, 2018). Results show the potential of computational methodologies to produce extensive urban solutions. This research, developed in a final graduation project in Architecture, aims at stimulating generative methodologies in undergraduate courses.

Keywords: *Terrain Vague, generative systems, parametric urbanism, genetic algorithms*

INTRODUCTION: PROBLEM CONTEXT

The introduction of large mobility infrastructures in Brazilian cities in the last 10 years, such as express bus lines (BRT in Portuguese), have not only helped to improve the transport system, but also brought new challenges regarding how to organise the urban tissue. The impact of these infrastructures on the periphery, in densely populated areas with low property values, plus a lack of planning, result in poor or abandoned spaces. The introduction of these infrastructures into the urban fabric produces urban voids, designated as *Terrain Vague* (Pereira, 2011).

Terrain Vague also represents a new hope due to its transformative potential. To express this idea in this work, we use the original French expression, *Terrain Vague*, as translation would restrict its meaning. Solá-Morales (2002) argues there is no English translation for the word. While in English, the word terrain refers to agricultural and geological concepts, the French relates to an expandable vision, as it is connected to the physical idea of a portion of land that has a potential condition to aggregate value to the city. But it is the second word, vague, that in English is only something empty, unoccupied, lacks the French sense of free, available and willing to establish a physical status. The French meaning also represents indeterminate, imprecise, blurred and uncertain, giving a temporal idea to the space.

The *Terrain Vague* (used here as plural) exist in areas of the city without function or social content. They are located in places connected by the infrastructures, but do not fully fulfil their social and economic functions, as they are occupied by structures without use or activity, and are vacant or empty (Borde, 2013). In spite of being areas of urban decay, they are also areas with potential for activism and social transformation.

Proposals for the *Terrain Vague* are scarce, considering the diversity, complexity and predominant presence of such land in contemporary cities. Besides conceptual studies, there are only a few studies proposing design solutions for these places.

There are political and economic factors involved in this process. The *Terrain Vague* are a by-product of property market operation, the private agents' behaviour and the public policy agency. It depends on the negotiating capacity and flexibility offered by future dynamics, present in political, economic and social objectives of the various planning models (Borde, 2013).

Therefore, the scope of the problem is vast. This work has no intention to solve all the *Terrain Vague* issues, but to contribute to developing a design methodology to act on the urban landscape.

HYPOTHESIS

We developed a generative system, using computational tools, to produce customised solutions for a set of empty spaces. Given the scale and number of *Terrain Vague* and their particularities, an individual resolution method, designing site by site is time- and resource-consuming. Since there is no systemic methodology to address this problem, we developed one for an urban area crossed by the Transcarioca Bus Expressway, on the Rio de Janeiro urban periphery. We analysed the Transcarioca along an 8-km stretch, identifying *Terrain Vague* in this area, resorting to a "visual grammar" (Bradley, 2010) to summarise their characteristics.

We chose a specific *Terrain Vague* site, and assessed the scale of the destroyed residual spaces that had not been reconstituted (Ferrara, 2000 and Borde, 2013); this selection was necessary to feed and test our generative system.

METHODOLOGY

We organised the methodology into four steps: Analysis, Classification, Generation and Selection. The first step focused on the macro scale, understanding the patterns of the environment, to identify and enumerate possible areas of action. In the city registries, we identified 90 areas, and grouped them according to their characteristics and relationship with the macro environment.

In the second step, we classified the group in more detail, and decided to focus attention on 50 areas to test the development of the generative system. To classify the areas, we developed a "visual grammar" derived from the iconic representation of the book, "Phylogenesis" (Zaera-Polo, 2003). In this book, the author identifies the formal generation of his design proposals according to a "visual grammar" that classifies them into different species, which we will describe later in detail. Although the methods used in Phylogenesis are analogue, it is possible to see an evolutionary sense in the proposed method, which we can implement with the support of computational methods. To define a "visual language", we identified common urban properties in the *Terrain Vague* and organised them into six categories (according to orientation, main axis and number of floors).

In the third step, we defined an algorithm based on these categories to generate geometric solutions for the 50 cases selected. The goal of this grouping was to automate the design process for all the *Terrain Vague* that have similar problems, albeit in different contexts. In the system, we defined three geometric operations according to three spatial types. The geometric operations were based on the work by Mari (2017), and each corresponded to the following spatial types: 1) public spaces, addressing transformation of spaces to be used as urban squares, defining the ground according to green and paved areas; 2) semi-public spaces, addressed by the addition of geometries to match the surrounding constructions. Thinking of using these nodes as activity-concentrating places, the system seeks the best position for the proposed geometries, according to shade, pavement lengths and free spaces; 3) semi-private spaces that subtract geometries from the total volume. The system evaluates the position of the subtractions according to the density of the operation, shade and open spaces. To develop these processes, we used visual programming (Grasshopper).

In the fourth and last stage, we evaluates the results obtained in the previous phase and then derived solutions. As it is an interactive process, the generation of solutions becomes a cyclical process, in loops, and so we used genetic algorithms to improve the results in this interactive process. Firstly, we relied on the concepts of Chiang (2017) and Alexander (2013) to define three criteria. The first criterion (Shade) analyses the total shaded area generated by the volumes in a site's open spaces (in the Rio de Janeiro region, shade is an invaluable asset). The second criterion (Open Space Hierarchy) compares the volumes generated and the resulting open spaces. The third criterion (Compactness) measures the volumetric linearity of the proposals. After generating solutions, the architect, like a geneticist, evaluates them according to each site's requirements. To influence the evolution of the results in an interactive way, we used the plug-in, Biomorpher that allowed us to intermediate genetic algorithms of quantitative development, with qualitative criteria by interfering with the selection of results, in every generation, considering multi-criteria analysis (Harding, 2018).

Analysis

We analysed an 8km region, bounded by the Penha and Irajá districts on the Rio de Janeiro periphery. From the analysis and identification of the environmental patterns, we selected 90 areas and divided them into 7 groups according to their relationship with the surroundings and intervention possibilities. These areas were:

Public squares: we identified 11 spaces cut and fragmented by BRT, most enclosed with walls.

Underneath infrastructures: 3 unused areas under viaducts.

Residual spaces: 50 buildings in ruins, not rebuilt. Some of them were illegal rubbish dumps or car parks, and the remainder enclosed with walls.

Walls: 8 buildings with blind façades and viaducts walls, surface and underground railways.

Idle structures: 5 abandoned structures, such as old service stations and unfinished houses.

Roundabout access: 8 cases that corresponded to intersection spaces between two or more roads.

Footbridge: 5 cases of long, narrow, thin, unsafe footbridges, some of which had fragile structures, while others were unsafe.

We started the study by addressing one of these spatial classifications, the Residual spaces, as they are greater in number, in many areas and contexts, but have similar problems.

Classification

The following step represents the beginning of the generative system: how we defined it and how many variables we considered. The Classification uses as its main reference the book, "Phylogenesis" (Zaera-Polo, 2003), which presents 36 architectural projects of the Foreign Office Architects (FOA), documenting the geometric primitives that generated the external form of each of the projects, grouping the projects into categories. To represent the "species", they use a "graft" that branches according to the categories and the projects. They illustrate these 7 categories with icons defining a "visual grammar" that we have reinterpreted and used to define rules to generate proposals.

Dividing the term "visual grammar", the first word, visual or visual language, consists of an alphabet of numbers, dots, lines and shapes, which can be organised into direction, tone, colour, texture, dimension, scale, and movement. On the other hand, the second word, grammar, is used to refer to the system and structure of a language. Considering that the elements of a visual language, as well as all languages, are organised by a grammar (Bradley, 2010), the term "visual grammar" refers to the structure of the visual elements of a language.

In this work, the vocabulary consists of visual elements of lines and shapes, forming icons in order to represent the urban parameters and to facilitate the communication methodology.

The classification defined 6 categories and 16 subcategories. Each category corresponded to an urban variable common to all the cases studied; in each subcategory, we used an icon to illustrate this variable.

Category a. Type of Space. *Goal:*To separate sort public, semi-public and semi-private spaces

Understanding that the urban infrastructures have been detrimental to the public spaces, some of which were already precarious, this work thought of introducing new places with different levels of use and activities. Firstly, we classified the cases for public use in relation to the existing local public squares. After this, we divided the remaining cases into semi-public and semi-private spaces. As Torisson (2008) defined, the first type of space is a private space accessible to the public, for instance a shop and a restaurant (nodal points or commercial concentration). It is open to the public, but has a certain private character. We can define the second as a space controlled by a front door access. They are not private because although closed they are accessible to outsiders, they are not public either, as cinemas and theatres (cultural activities).

Urban variable: distance between public squares and nodal point selection.

Subcategory:

EXTERNAL:

Cases that have potential as a square or public space. We looked for squares within a 10-min. walking distance, or 400m, to define new squares in the empty spaces.

Cases that have nodal point and semi-public space characteristics. We organised 50 cases in a list, setting a nodal point every 400m. These are activity-concentrating points.

INTERNAL: The remaining cases had semi-private spatial characteristics.

Category b. Layer Type. *Goal:* sort the cases by the number of floors

Urban variable: total building height obtained by the difference between the buildings and the ground level according to the Rio de Janeiro database.

Subcategory:

SIMPLE EXTERNAL: ≤ 1 floor.

COMPOSITE EXTERNAL: ≥ 2 floors.

SIMPLE INTERNAL: ≤ 1

COMPOSITE INTERNAL: ≥ 2 floors.

Category c. Predominant Orientation. *Goal:* sort the cases by the number of accesses

Urban variable: number of accesses.

Subcategory:

UNIDIRECTIONAL: one access.

BIDIRECTIONAL: two accesses.

TRIDIRECTIONAL: three or more accesses.

Category d. Predominant Axis. *Goal:* sort the cases by predominant axis.

Urban variable: area squared and total height. It is the relation between the heights squared divided by the case area

Subcategory:

HORIZONTAL: the area is larger than the square of the total height.

VERTICAL: the square of the total height is larger than the area.

Category e. Geometric Operation. *Goal:* sort geometric operations by categories.

Urban variable: insolation studies, total building height, distance between local public squares and nodal point selection.

Subcategory:

TRANSFORMATION: "SIMPLE EXTERNAL" with public square characteristics. Geometries subjected to transformative actions, such as bend, tilt, divide, twist, overlap and rotate.

ADDITION: "EXTERNAL" with nodal characteristics. Geometries subjected to addition, such as expand, extrude, inflate, branch, join and move.

SUBTRACTION: "INTERNAL". Geometries subjected to the subtraction, such as sculpt, compress, fracture, chamfer, tighten, inlay, extract and inscribe.

Category f. Contextual Relationship. *Goal:* sort the cases by proximity to BRT stations.

*Urban variable:*distance to BRT station.

Subcategory:

INDEPENDENT: BRT stations beyond a 100m radius

DEPENDENT: BRT stations within a 100m radius.

To finish the classification, we represented the data using three types of visualisation. We used a different colour for each case and presented a summary of its category and adding an icon (visual grammar).

We first used a quantitative map illustrating the cases by categories and subcategories, showing the quantity and percentage within each classification. The data is presented in a clockwise direction, starting by identifying the case number, the number of floors and the area squared, and then connecting it to the corresponding subcategories through lines.

The second map we used is a geographical map that illustrates all the case contexts with their respective classification summaries. Some cases are related to the buildings of the book, "Phylogenesis" (Zaera-Polo, 2003) that have the same order of classification.

The third map we used is qualitative. Each branch division sorts the cases according to the previous classification. For example, in the first column, the EXTERNAL cases go upwards and the INTERNAL

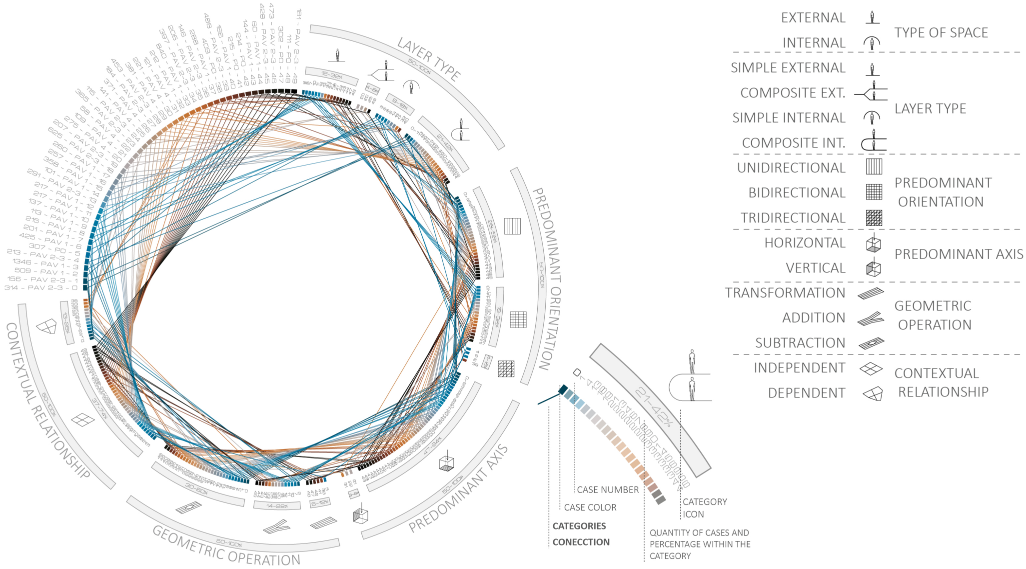


Figure 1
The Qualitative map

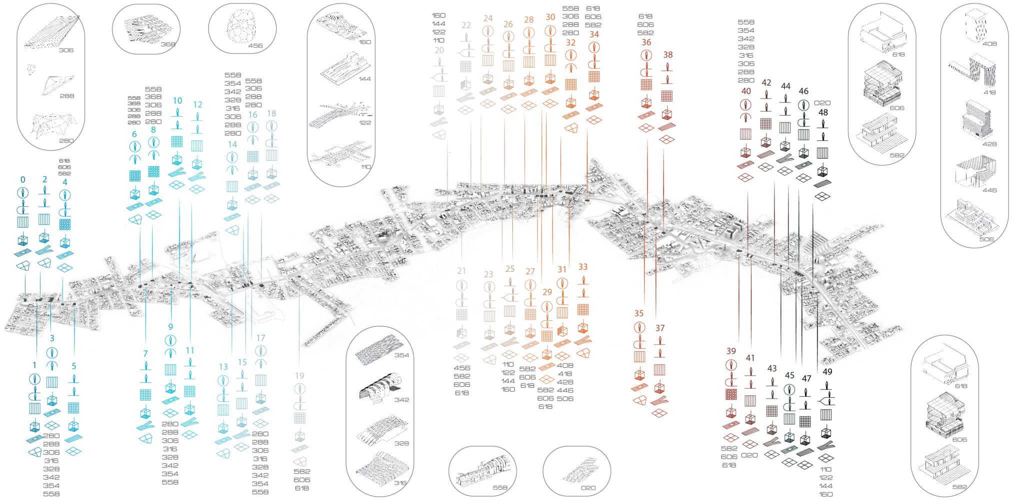


Figure 2
The Geographic map

downwards. The Generation step below presents a display of the branches.

Generation

Based on the categories, the third step documents the algorithm construction, illustrating the geometric development of the solutions. The Generation uses as reference the book, "Operative Design: A catalogue of Spatial Verbs" (Mari, 2017). The book presents a series of operations used as "kick-starters" for compelling spatial exploration. It uses three main verbs, displace, add and subtract, which we reinterpret and develop in this work.

The next graphs are related to the qualitative maps by their columns, in order to illustrate the changes in the algorithm. Each branch created corresponds to a new rule.

Transformation, in public spaces. The first process transforms the ground; modifying, scaling, shortening or extending it. Column I displays the type of operation and represents the degree of deformation according to the user's need. For instance, with the majority of children in the surrounding area, the system works with more profound transformations on the ground. Column II configures the grid to apply in the proposal. As initial grid possibilities, we established a striped division with a minimum width of 3m. Column III describes the stripe orientation. We decided that their direction would always be towards the façade of the BRT lane. Column IV combines the stripes and the flat spaces, paved areas, or transformed green areas. We can transform each space into three types of wave frequency, represented in Column V, and it has a direct relation with Column I, the user's need. The last line shows some of the results.

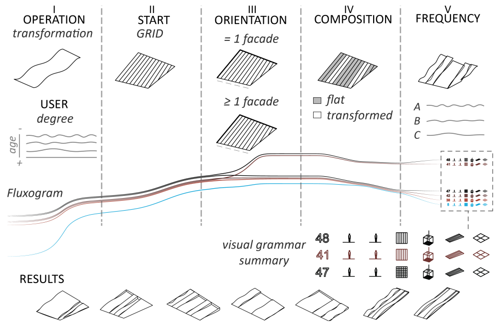


Figure 3
Transformation process

Addition, in semi-public spaces. The second process addresses the addition of geometries to match a volume. Thus, Column I shows the type of operation and the volume offset according to the user's requirements. For example, if the proposed site has narrow pavements, the system can limit the occupation volume, in order to increase the space outside. Column II configures the grid to apply in the proposal and the number of floors. We set as an initial grid, a 3mx3m cell division that we replicate in the upper floors. Column III describes the grid orientation. We decided to always orient it towards the façade of the BRT lane. Column IV corresponds to the merged cells on each floor, and Column V represents the volume formation. The last line shows different results.

Subtraction, in semi-private spaces. The third process subtracts geometries from an initial volume. Column I shows the type of operation and the subtraction amount according to the user's requirements. For example, if the goal is to generate proposals with large openings, the system calculates bigger subtractions and in a greater number. In Column II, we configured the maximum occupancy volume and the type of subtraction according to the number of floors. In one-floor cases, we split and trimmed the volume; and in two or more floors, we used multiple-size cubes to subtract the volumes. Column III describes subtractive geometry orientation. As an initial experiment, we established orientation of all the geometries perpendicular to the corresponding façade. The value of orientation angles corresponds to the access case number. Column IV illustrates the subtraction process, and Column V represents the volume shape. The last line shows some proposal results.

As seen in the Generation step, each geometric operation has a different algorithm logic, based on the category and subcategory we had defined previously. Therefore, we made this process to start experimenting with volumetric solutions, so that they could be refined with the system development. As it is an interactive process, the solution generation is a cyclical process, in loops, using genetic algorithms to improve results (Fischer, 2000). Next, we introduce the selection process.

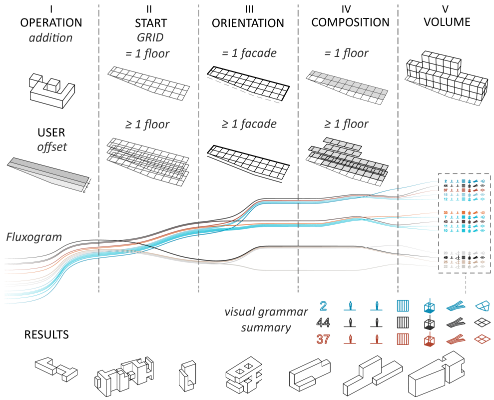


Figure 4
Addition process

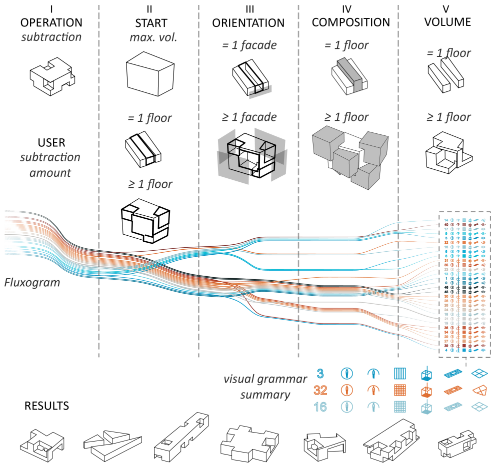


Figure 5
Subtraction process

Evaluation and selection

In the fourth and last stage, we initiated the evaluation and selection of the multiple results generated in the previous steps, in order to filter and identify the best proposals. Firstly, we created three analytical criteria so the proposals are on a normalised scale.

Thus" we could compare the values. After this, we evaluated the proposal's quality.

We used the plug-in, Biomorpher that allowed us to interfere with each evolutionary cycle, by introducing qualitative criteria. The genetic algorithms for optimisation rely on quantitative values, so Biomorpher allowed us to introduce qualitative criteria to include in the next development cycle according to multi-criteria (Harding, 2018).

Criteria. We defined three criteria according to three characteristics of the cities: shade, open space hierarchy and urban density. This step used as references the article, "Measuring Neighborhood Walkable Environments" of Chiang (2017) and the book, "A Pattern Language" of Alexander (2013). The article discusses walkable environments in the city, and we used its concept of street connectivity and pavement quality to evaluate if a proposal encouraged alternative paths within the site. The book demonstrates three scales of city patterns: towns, buildings and other constructions; and it shapes the environment according to these patterns, in order to solve a stated problem. We based our methodology on towns and building patterns, where discussion about the relation between public/private spaces and the volumetric composition of urban areas takes place. We used these urban concepts to measure the dimensions and scales of the volumes proposed and their open spaces.

Therefore, to choose the best solution, we evaluated each characteristic of the solutions generated.

Shade (S): Quantifies the larger shaded area in summer and the smaller shaded area in winter produced by the volumes generated in its open spaces.

$$\frac{(1-SU)x2.5+WIx0.5}{3}=S \qquad (1)$$

WINTER-WI=Σpt/ΣptSUN; SUMMER:SU =Σpt/ΣptSUN

Open Spaces Hierarchy (OSH): measures the hierarchy of the open space area in relation to the volume area generated, through crossing or access to the site, proportion and dimensions of the proposed open space.

$$\frac{0.5xCRO+1.75xPOS+1.75xDOP}{4}=OSH \qquad (2)$$

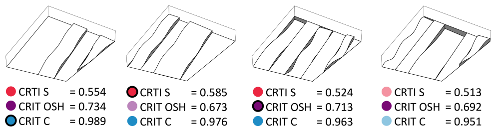
CRO= Number of crossings; POS = Proportion of Open Space (open space area/total area); DOP = Dimensions of Open Spaces (width/length)

Compactness (C): measures the linearity of the geometry. The larger the C, the more compact and linear the volume, and the smaller the façade area.

$$1-\frac{Asur}{Vol}=C \qquad (3)$$

Asur = Area of Surfaces; Vol = Volume

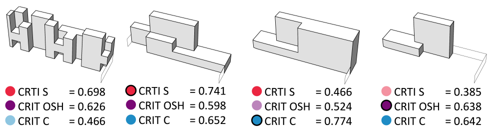
Evaluation. The quality criteria is associated to the evaluation of the geometry generated. In the context of multiple generation possibilities, the designer makes the analysis and observes the proposal's fulfilment to decide. To make it clear, we displayed four examples of geometric operations to develop the initial results.



Transformation, in public spaces

Figure 6
Transformation, in public spaces

1. Higher C criteria: more compact geometry
2. Higher S criteria: more shade in the straight stripes
3. Higher OSH criteria: more rectangular / narrow open spaces
4. Lower S criteria: more insolation with straight stripes.



Addition, in semi-public spaces

Figure 7
Addition, in semi-public spaces

1. Lower C criteria: more sinuous geometry
2. Higher S criteria: more shade in the open space
3. Higher C criteria: more compact geometry

4. Higher OSH criteria: bigger open space

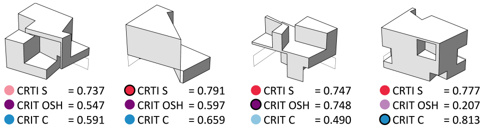


Figure 8
Subtraction, in semi-private spaces

Subtraction, in semi-private spaces

1. Lower S criteria: more insolation in the open space generated
2. Higher S criteria: more shade in the open space
3. Higher OSH criteria: bigger open space
4. Higher C criteria: more compact geometry.

When it comes to the transformation process, we focus on the topographic deformation, the S criteria (Shade) is naturally lower, and less decisive in the selection of the final solution. We evaluated these surfaces using OSH criteria, prioritising narrower greener areas. Precisely because they are public squares, this criteria in relation to the other geometric operations should have the highest evaluation to prioritise green spaces. We measured the C criteria by the ratio between the surface area and the total volume. Referring to topographies, the criteria resulted in high values with little variation, making the selection process difficult.

As for the addition process, the S criteria analyses the shading of the open spaces we proposed. The values have variations and they are consistent with the total area of the open spaces. The OSH criteria evaluates the open space proportion in relation to the total area; to create new accesses, contributing to new routes in the city. However, the values obtained still had little variation. We measured the C criteria by the ratio of the surface areas to the total volume. The values achieved were consistent with the analysis.

Referring to the subtraction process, the S criteria analyses the shade of the open space solutions. As they are subtracted volumes, their criteria values should be higher, because they provide greater sun protection. The OSH criteria evaluates the proportion of open spaces in relation to the total area. The values obtained are consistent with the analysis. W measures the C criteria by the ratio of the surface areas to the total volume area. The values obtained were consistent with the proportion of proposal subtractions.

As a first approach, the results are significant, although the algorithm could be improved. This experiment proposed and tested a methodology to improve the results.

Selection

In the last step, we evaluate the solutions to satisfy the requirements. As an exploratory model, we selected one proposal for each geometric operation and briefly illustrated their uses.

RESULTS

We created and developed a methodology for a generative system to find solutions for the *Terrain Vague*. We analysed and mapped 90 sites. We proposed a visual grammar with 6 categories and 16 subcategories that codifies urban variables to generate occupation solutions. We developed an algorithm associating three geometric operations with three types of space: transformation in public spaces, addition in semi-public spaces, and subtraction in semi-private spaces. Associated with this, we developed a recursive method to generate solutions, improving them in cycles. The volumes were selected by 3 criteria: Shade, Open Space Hierarchy and Compactness of the proposals. Finally, with our methodology, we produced a family of 50 site solutions.

DISCUSION

We developed this research in a final graduation project in Architecture, which is not usual in Brazil, nor in most universities in South America. The University does not teach the knowledge that is necessary to develop such a system in the regular compulsory Architectural disciplines. It is only possible with a special interest and dedication to learning new subjects, in optional disciplines in conjunction with research workshops developed at LAMO, like "Defy-

Figure 9
Transformation, Addition and Subtraction examples, respectively.

ing Gravity" (Henriques, 2015), and, more recently, "Form Finding and Generative Systems" (Henriques, 2018). The main objective was to make a generative system capable of generating multiple options. In this sense, the focus was on the development of a new tool rather than its accuracy for final solutions. Regarding the reviewers' comments, we would like to add that future research could also address the social concerns.

By defining geometric rules, the generative system produced unforeseen or unexpected volumetric solutions, expanding the design possibilities. This happened for two reasons. The first is because the demand includes a randomness factor, present in the dispositions and scales of the transformation elements, addition and subtraction. The second is the restriction of these elements, allowing interaction with the genetic algorithm through quantitative restrictions, Shade, Open Space Hierarchy and Compactness; and qualitative, volumetric composition, which the designer chooses.

The proposed methodology and the results obtained demonstrate the feasibility of developing a generative system. The research intended to be a proof of concept. In this regard, the criteria and values were not a concern per se or the centre of the research. Rather, we favoured development of an evolutionary system to generate families of solutions for the *Terrain Vague*, which we can improve in the future.

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