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Comparative Analysis of Geospatial Visualization Tools for Urban Zoning Planning

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Abstract

The collective management of urban environment is a challenging task. Although considering the individuals and their values helps to build environments that are closer to the user's expectations, the identification of these aspects is not an easy task. Considering the potential of exploring visualization tools to support public participation, this paper compares two different 3D tools based on parametric modeling. Reinforcing the relevancy of both methods in promoting the visualization through the process of regulating the urban landscape resulting from the urban parameters, this paper aims to evaluate their performances concerning time consumed, training requirements, results and applicability.

Keywords 3D Modeling; Parametric Modeling; CityEngine; Grashopper3D; Visualization

INTRODUCTION

Brazilian rules that shape the urban built environment are usually defined by the Master Plan, and they indicate for each parcel of land, land occupation indexes and parameters according to each different zoning. Due to the way it is presented in urban regulations, as tables and indexes, Brazilian zoning codes can be somewhat difficult to understand and decode even by architects and urban regulators. For Brazilian citizens, the application of these parameters can be even more challenging to understand, as well as their volumetric representation and impact in the city's landscape. This results in an uninformed participation on the planning and management process concerning Brazilian zoning codes.

In presenting a case study of the city of Fortaleza, in Brazil, this paper compares two different 3D simulation tools with the aim of promoting future collective understanding regarding these Brazilian urban regulations, which limits the occupancy of an urban unit (lot).

On one hand, it presents a tool based on the spatial logic of Geographic Information Systems that is focused on the modeling of urban environments. In this step, ESRI's™ CityEngine platform is used to explore the potential of translating a set of urban parameters from Fortaleza into its possible volumetric result for the landscape. Through the application of procedural modeling, this tool allows for the simulation of morphometric envelope of buildings.

On the other hand, the same methodology is applied to a tool based on the exploration of the forms. In this case Rhino's plugin Grasshopper helps to explore the forms resulting from the combination of variables, values and rules. Reinforcing the relevancy of both methods in promoting the visualization through the process of regulating the urban landscape that results from the urban parameters, the paper aims to evaluate their performances concerning time consumed, training requirements, results and applicability.

METHODOLOGY

This research was developed in two steps. An overall literature review of relevant analogous work will be presented in the introductory step, followed by a bibliometric analysis of related three-dimensional and georeferenced urban planning models. Another analysis focused on the different visualization tools used in public management policies follows next.

The literature review was performed using the online platform Web of Science, because it is considered a broad and multidisciplinary repository for scientific research. The term searched was "3D GIS," since its search scope includes three-dimensional georeferenced softwares. We associated "3D GIS" with a second term, "Urban Planning," and then with "procedural modeling." Since "procedural modeling" is similar to "parametric modeling" in Brazil, a third search was performed using "urban planning" in association with "parametric modeling" and "Brazil." The literature review was limited to the last 5 years, since there was a surge in research publications related to the topic starting in 2013.

A database was created with 119 papers in order to classify according to the following criteria: publishing date, title, authors, publishing mediums, country of origin, research goals and abstract. Different groups, fields and types of research were also separated in different categories.

In the second research step, two different urban three-dimensional modeling tools were selected for a comparative experiment: ESRI's™ CityEngine and McNeil's™ Grasshopper. Similar area of analysis and modelling objectives were considered in both simulations in order to detect any possible variables that could influence the performance of each tool. The simulation of Fortaleza's current urban parameters was the primary research goal in either simulation. The city of Fortaleza is known as one of Brazil's major coastal city, which is currently undergoing a rapid coastal verticalization.

The tools' selection sought to consider different ways to simulate and model similar urban scenarios. Whereas CityEngine uses GIS logic to develop its modeling and simulations, Grasshopper uses a geometric CAD logic. The potential of translating a set of Fortaleza's urban parameters into its corresponding maximum volumetric envelope was explored in both tools, and allowed a morphometric visualization of the developed urban landscape.

The following attributes were considered for performance validation of both tools: time consumed to develop the script, time consumed by the training and understanding of the tools logic, overall results, and applicability of each developed model. Finally, the results are presented and analyzed in chapter Discussion and Conclusion.

LITERATURE REVIEW

BIBLIOMETRIC ANALYSIS

The bibliometric analysis shows that there are two main group of researches regarding the subject. The first is directed to the improvement of techniques, approaches and modeling, and has brought technological progress to the most diverse areas of Urban Planning. The second group has focused on the properly application of the tool in the various fields of Urban Planning.

Billger et al. (2017) had a similar framework when they did a review identifying the challenges for the implementation of visualization tools in Urban Planning through an analysis of 114 articles that were published between 2004-2014.

According to the bibliometric analysis, researchers focused on the improvement of techniques and models represent 68% of published articles, and conduct researches in the areas of Computer Science, Geography, Remote Sensing, Science of Image and Photo Technology, according to table 01.

Table 1: Bibliometric Analysis - Improvement of Techniques.

TECHNIQUES IMPROVEMENT		
RESEARCH GROUP	NUMBER OF PUBLICATIONS	RESEARCH AREA
Comparative studies between tools	04	Computer science
Development of new models, technique, and approaches	50	Computer science / Geography / Remote sensing / Image Science and Photographic Technology
Integration and interoperability between tools	14	Computer science / Geography
Data (management, recovery, collection)	13	Remote sensing / Computer science

From the above works, 15 were classified in more than one research group: 08 publications from "Integration and interoperability between tools" class, and 06 publications from "Data (management, recovery, collection)" class were also classified as "Development of new models, technique, and approaches." In addition, there was 01 work from "Data (management, recovery, collection)" using methods of "Comparative studies between tools."

Furthermore, the researchers focused on the application of 3D GIS tools in Urban Planning correspond to 21% of the analyzed works. At least half of them are associated with urban density and vertical urban growth studies, while the remaining ones are directed to public participation, applicability of the tool in Urban Planning, Walkability, among others. While publications about "Techniques Improvement" are more frequent in Seminars, Conferences and Symposiums, publications about the application of 3D GIS tools in Urban Planning are more frequent in journals. Also, the majority of Urban Planning researches (72% of publications) shows case studies of cities, while only 35% of publication about "Techniques Improvement" presents case studies of cities.

PUBLIC PARTICIPATION USING VISUALIZATION TOOLS IN URBAN PLANNING

Billger et al. (2017) found 5 challenges for implementation of visualization tools in urban planning: the challenge of integrating data, the challenge of representing data, the challenge of avoiding misinterpretation, the challenge of managing new visualization tools in established organizational structures, and the challenge of developing engaging dialogue. The authors concluded about the potential of visualization tools with faster computers, better simulation models, an increasing amount of available data, and increasing use of digital interaction tools, and now consider the need to achieve all this potential of visualization tools and process for dialogue as well as how these can be implemented.

The driving force for development of visualization based tools for dialogue is the desire to support sustainable city planning through information sharing, analysis, development, presentation and communication of ideas and proposals throughout the planning process (Billger et al. 2017).

In Scotland, Wan et al. (2005) used 3 softwares in a new combination of visualization tools to develop three-dimensional models to promote public participation in green areas intervention projects. The results showed that 3D visualization associated with interactive communication influences participation and decision making in urban planning.

Dambruch and Kraemer (2014) developed a web-based portal model using three-dimensional models to promote public participation in urban planning based on the Botton-Up engagement process. According to the author, in the traditional urban planning model, planners present their plans to decision-makers who begin the implementation process, known as the Top-Down approach, currently considered unable to cope with the growing complexity of sustainable urban management.

Researches related to urban densification and consequent vertical urban development cites the importance of public involvement in decision-making. In this group of researchers, the use of parametric modeling of the urban environment has been highlighted.

Guo et al. (2017) applied 3D spatial analysis technology in assessing the impacts of change in development control parameters, with the case study in Hong Kong. The findings from this study provide objective data and scientific methods which enable the government and other stakeholders to objectively assess the environmental impact of land development density in high density cities like Hong Kong, have rational discussion and debates, and make effective and informed decisions (Guo et al. 2017).

Koziatek and Dragicevicet (2017) used parametric modeling to analyze areas suitable for vertical urban development (VUD) in the city of Surrey, Canada using the geosimulation method named iCity 3D. The study, therefore, aims to integrate land selection evaluation and spatial procedural modeling approaches on an irregular spatial tessellation to advance 3D geosimulation modeling of VUD process over space and time

Grêt-Regamey et al. (2013) showed how interactive rules embedded in a 3D GIS-based procedural modeling environment can assist in making urban ecosystem services trade-offs explicit for sustainable urban planning. Parametric procedural modeling approaches using shape grammars offer powerful city modeling and visualization tools enabling quick visualization of complex city models, evaluation of alternatives, and iterative design workflows (Grêt-Regamey et al. 2013).

Moura (2015) adopted the framework of Geodesign with procedural modeling to simulate a future urban landscape considering the current urban parameters and studies about the possible transformations in Pampulha, an area in Brazil planned by Oscar Niemeyer.

There is a lack of a methodological process that clarifies the roles of different actors (stakeholders and staff), promotes visualization of the current situation, permits the understanding and evaluation of possible proposal, and permits feed-back in the necessary phases according Steinitz (2012 apud Moura, 2015, p. 323).

Parametric modeling adoption makes it easier for planners to act as decoders of collective values, not limiting themselves to drawing urban space according to their personal values. This brings up interest in results of urban design, and not only to read about the geniality of the urban planner, to focus in architecture results and not only on the architect as an artist (Moura, 2015).

MASTERPLAN AND URBAN PARAMETERS OF FORTALEZA CITY

In Fortaleza, the Participatory Master Plan (PDP - Plano Diretor Participativo) sets the urban parameters for each one of the zones that composes the city's territory. Through the urban parameters, densification is encouraged in some areas and restricted in others, depending on the infrastructure, urban services and existing environmental conditions. The Coefficient of Utilization, (CA - Coeficiente de Aproveitamento), is an index that indicates the total amount of construction that is allowed to be built; the permeability index (TP - Taxa de Permeabilidade), which is a rate of the parcel that has to be permeable; index of occupation (TO - Taxa de Ocupação), which is the rate of the parcel occupied by the horizontal projection of the building; height limit (H); lot fraction (FL - Fraçao do Lote) restricts the number of units in a parcel; and minimum dimensions of the lot.

Urban parameters such as TP, TO, CA, and H associated with the setbacks, defined by the a law called Use and Occupation of Land (LUOS - Lei de Uso e Ocupação do Solo), compose the physical form of land occupation in Fortaleza. The setbacks vary according to the activity, the built area, and the street classification in which the parcel is placed. Also, depending on the final height of the building, there may be increments to the setbacks. Therefore, the greater the number of floors is, the greater is the setback, which is applied to all the floors.

RESULTS AND ANALYSIS

It was chosen a zone, for modeling and simulation, which would allow greater intensification of occupation, as much as an increased level of built density, which is the beachfront ZO-4 (Zona de Orla - 4), in the Meireles and Mucuripe neighborhoods, according to PDP de Fortaleza (Figure 1).

The zone ZO-4 is the one that presents the greater CA (CA=3.0), even allowing an increase in 1.0 of this index for cases of Hotel use, according to PDP. Recently, in this zone, there was an approval of a residential development using CA = 6.0, and height of 126m, which overcomes in 54m the authorized by the PDP.

CITYENGINE SIMULATION

The CityEngine platform was used to translate the set of urban parameters of an area of Fortaleza, to its volumetric result for the city’s landscape. Through the application of parametric modeling using cga rules, the tool applies the urban parameters defined by the zoning in a way to simulate the maximum possible occupation considering a parcel division.

In this first step of simulation, using CityEngine, the model considers possible future scenarios through the application of aggregations between the underutilized parcels. The underutilized cover parcels of multi-familiar residential use, commercial use, and services use that apply CA up to 1,0. Thus, it was possible to aggregate neighbouring underutilized parcels to reach larger areas for occupation. The parcels identified as underutilized were presented by the following figures (Figures 1 and 2).

Figure 1: underutilized parcels of the study area. Source: authors.

Figure 2: simulation identifying the underutilized parcels of the study area. Source: authors.

In order to turn the simulation closer to the dynamics of real estate market of Fortaleza, the study promoted a research of the building projects permits issued between 2015 and 2017 in the city. The analyzed information included the parcel's area, location, use, total built area of the project, and description of the urban parameters for each one of the developments. All the information was extracted from the internal system of the municipality whit authorization of SEUMA (Secretaria Municipal de Urbanismo e Meio Ambiente). From the more than 1.100 permits were issued over the analyzed time, the study identified the largest ones to analyze their practiced urban parameters. From all the gathered information,the developments were classified according to their characteristics in a way to contemplate 4 main classes of occupation:

a. Parcels of over 1.500m²: this is considered the class of maximum occupation as the units reach both the maximum CA and maximum height (24 floors or 72 meters high). The majority of the developments are intended for multi-family residential use.
b. Parcels between 1.500m² and 1.000m²: these units are considered of high occupation as they reach the maximum CA. However they don't reach the maximum height, which varies from 17 to 20 floors. The uses are of multi-family residential and hotels.
c. Parcels between 1.000m² and 600m²: considered a class of medium occupation as only a few projects reach the maximum CA, with the height of up to 16 floors. There is an increased number of building of hotel and commercial uses.
d. Parcels lower than 600m²: presents a reduced CA with heights of up to 3 floors and are random activities such as small shopping centers, retail stores, provision of services.

From the definition of classes, the practiced urban parameters were analyzed considering each class. The translation of parameters into volumes implicates in a careful study of them as, in general, they are presented as ratios and indexes. In order to apply the set of parameters for each parcel, a cga rule was structured covering operations of both calculation and visualization, considering the following steps (Figure 3).

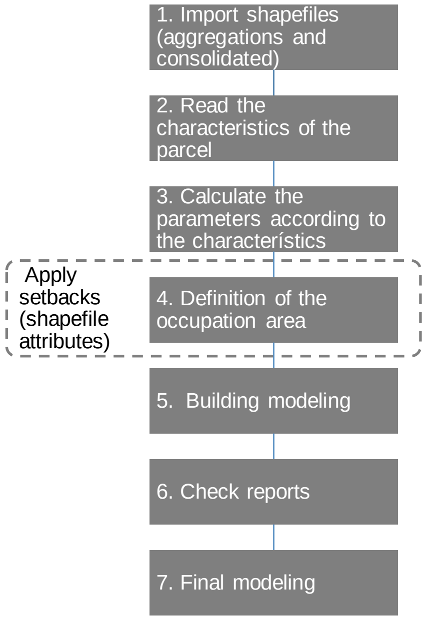


Figure 3: flowchart of CityEngine cga rule steps. Source: authors.

Prior the importation of the shapefiles the layers need to be necessarily treated. As the methodology works with static models in CityEngine instead of dynamic ones, there is no way to alter the configuration the parcels division. Thus, the aggregations were performed using Grasshopper, then exported to shapefiles and reunited with the consolidated parcels to be imported into CityEngine. Also, the shapefiles needed to be prepared with all the parameters used by rule, such as frontal, side, and back setbacks, in order to be read by the cga rule.

After importing the shapefiles into CityEngine, the rule starts with the reading of the characteristics of the parcels such as its area. After that, the rule calculates the values of urban parameters according to the parcel characteristics and shapefile attributes. Thus, although the whole study area is placed in only one zoning, the rule may be applied to areas with multiple zones as long as the parameters are specified by the shapefile attribute table.

Then, in the fourth step, the rule defines the occupation area, analyzing the applicable setbacks and checking the coherence with the TO.

After that, the model generates the buildings volumes. It is possible to generate together with the volumes, some reports about some aspects of the objects such as total constructed area. So that, the rule finished with the option of differentiating with colors each one of the classes. The resulting simulation is shown by figures 4 and 5.

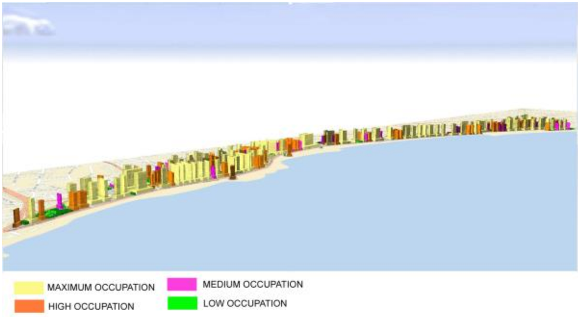


Figure 4: final model of CityEngine simulation. Source: authors.

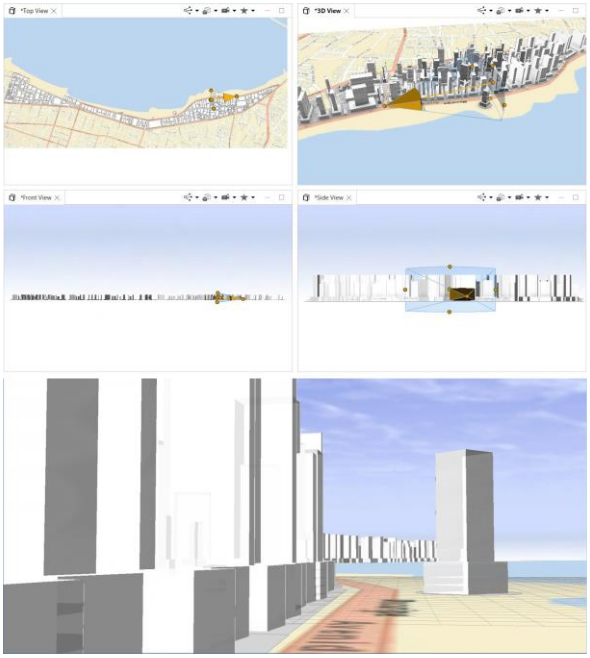


Figure 5: view corridor from final model of CityEngine simulation. Source: authors.

GRASSHOPPER SIMULATION

The simulation of scenarios consists of a parametric model developed in Grasshopper. The parametric model algorithm considers the following steps (Figure 6).

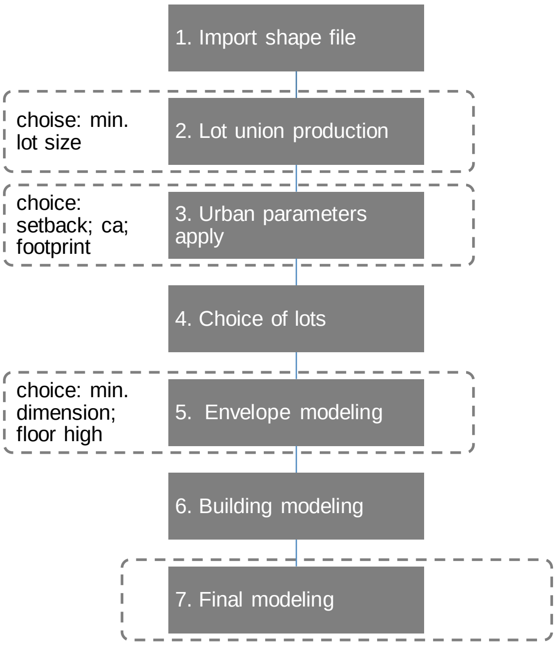


Figure 6: flowchart of Grasshopper algorithm steps.

The Figure 7 below shows the algorithm such as viewed in Grasshopper's interface:

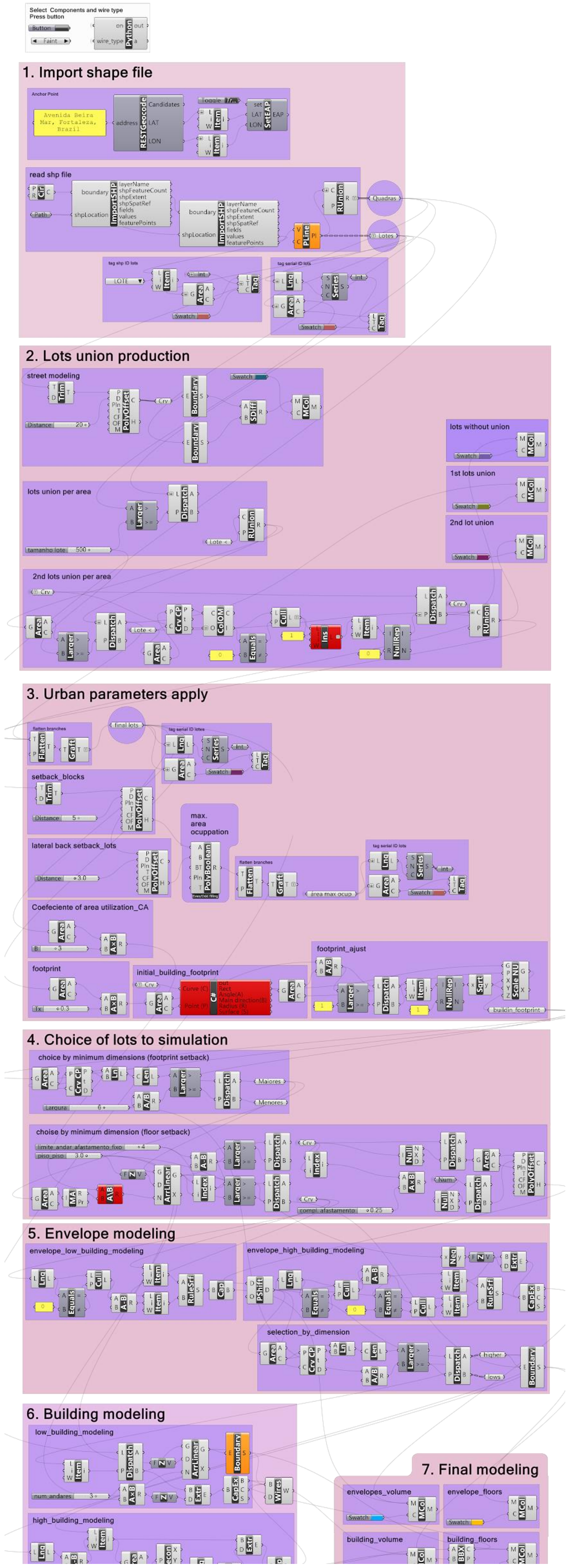


Figure 7: algorithm in Grasshopper. Source: authors.

Firstly, the parametric model processes a database by importing a shapefile (shp) that was previously prepared using ArcGIS, with spatial reference in UTM WGS-84 coordinate system, and modeling the study area in Fortaleza.

In the second step, the algorithm allows the user to set a size (area) lot to be process the union of them. This step has two stages, in first one, the lots with lower area sated are union in case of neighborhood relations. In the second stage, the lower area lots that don't have border with other lower area lots are union with the greater area lots that have neighborhood relations.

In the third step, the urban parameters are applied. It's possible to set the front setback, the lateral and back setback; the coefficient of utilization (total construction area); and the TO (index of occupation).

The fourth step selects the adequate situation to model the simulation. The selection is made by choosing a minimum dimension size of the area (in horizontal plan) resulted after the setbacks. The algorithm separated the lots of greater dimensions to model high building and the lots of lower dimensions to model low building (it's possible to choose one to four floors).

The fifth step models the setback envelope. This envelope shows the possible volume to be occupied by the building considering the setbacks. Because of an increase of the setback according with the height, the setback envelope has a pyramid shape after the 4th floor. The envelope is used for a visualization purpose only.

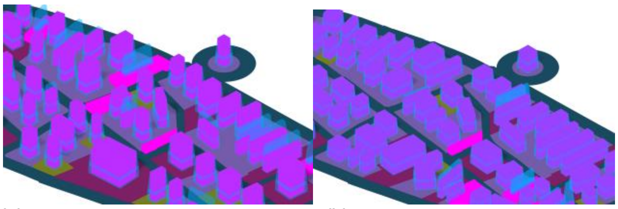
The sixth step models the building volume and its floors. The last steps join the streets, the envelopes and the buildings, and apply a color to the objects.

It was simulated two situations. The first simulation sets the minimum area for lots union in 1.000m², a TO of 0.2 and a minimum dimension of buildings floor in 6 meters. The second simulation sets the minimum area for lots union in 500m², a TO of 0.3 and a minimum dimension of buildings floor in 8 meters. For both situations, the simulations compare the envelope setback, which results in a pyramid shape, and the building volume, which appies the greatest setback to all the floors (Figure 9). The figures 8 to 14 show the results in a comparative way, with sub-caption "a" referring to the first simulation, and sub-caption "b" referring to the second simulation.

(a)

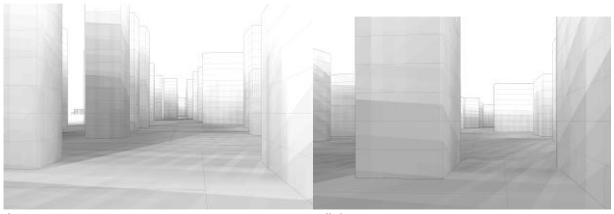
(b)

Figure 8: lots union. Source: authors.



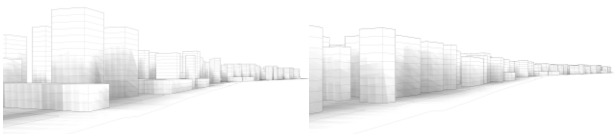
(a) (b)

Figure 9: setback envelopes and buildings volume. Source: authors.



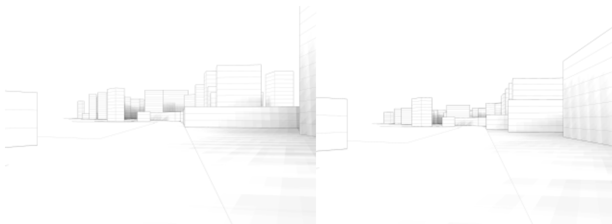
(a) (b)

Figure 10: scene 1. Source: authors.



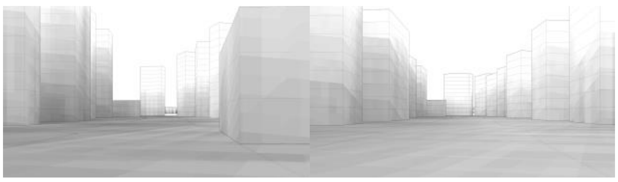
(a) (b)

Figure 11: scene 2. Source: authors.



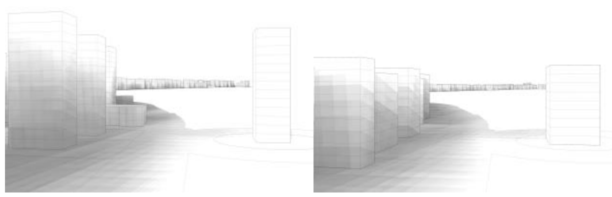
(a) (b)

Figure 12: scene 3. Source: authors.



(a) (b)

Figure 13: scene 4. Source: authors.



(a) (b)

Figure 14: scene 5. Source: authors.

DISCUSSION AND CONCLUSION

The study was based on comparisons among parametric modeling applications, but achieved greater goals than this, such as complementary discussions. The study group of the present work has investigated ways of visualizing urban parameters present in Brazilian master plans, according to different aspects, ranging from the understanding of how they arose to the impacts of having a landscape so conditioned by exclusively morphometric references. And even if urban landscape management based on current parameters was considered effective, it's important to investigate if the values applied on laws are feasible.

The big question is: is the landscape consciously chosen and authorized by public administration, citizens and the real estate market, or is the Brazilian urban landscape the result of numbers placed on a table, without being seen in advance where they can lead us? This approach is unprecedented and was initially proposed by the research group.

The article compares 3D modeling tools and visualization support. It is observed that the two applications compared, CityEngine and Rhino 3D + Grasshopper, are of different natures and preferential applications in the architecture and urbanism sector. CityEngine is associated with the GIS - Geographic Information System group, mainly to ArcGis applications. In this sense, although it may be used on architectural scale, its main uses are in the scale of the lot, the city and the landscape. Rhino 3D is widely used by the group of object designers and architects, and when used in urban scale is also associated with design of projects. Due to these differences, the following limitations and potentialities were observed:

a. Georeferencing and consideration of Earth reality: CityEngine, as a GIS, considers different models of Earth representation, being able to perform performances in large areas and considering the terrestrial curvature. Rhino 3D, based on CAD, uses a Cartesian plane of reference and places a reference position for the data, but it cannot be considered “georeferencing” in the sense of the word. This limitation can lead to difficulties in large-scale projects.

b. Topological relationships for the recognition of lots sides:

   CityEngine should have full conditions and facilities in topology issues, based on GIS. However, limitations were observed in the recognition of neighborhood relations. When the application performs the construction of the representation of an urban area through the tools themselves, it already draws the spatial reality in a continuous way, in the logic of territorial parcels, and is able to recognize the side of the lot that corresponds to its frontal line, due to its connection with the street. However, when shapes are imported and they are separated as blocks, lots and paths, it does not identify what the front side of the lot would be that correspond to the paths, requiring the user to manually identify them. On the other hand, once the frontal sides facing the roads are informed, it applies its topological tools and identifies the lateral sides and the back sides automatically.

   The Rhino 3D has tools to program the topological recognitions, which was possible to identify the frontal facing the roads. However, all other sides of the lot are considered sideways, lateral sides, without the possibility of applying back sides setbacks diverging parameters other than the lateral sides. It will be up to the researchers to then plan a logic for this separation.

c. Topological relations of neighborhood recognition of lots: Using CityEngine, the researchers were unable to include in the rules to identify lots according to some conditions (limits of areas) that were also side by side, using logics of neighboring. It was important to the studies to simulate the possible union or incorporation of the parcels into the production of a single parcel, following the interests of the real estate market. In Rhino 3D it was possible to model an algorithm for this execution, which is very useful to simulate processes for the incorporation into big lots by purchase and sum of small lots.

d. Topological relationships of drawing of distances defining the internal area to the lot where the building can be designed: In CityEngine, by its nature GIS, it acts very adequately in drawing processes that require adjustments of closing of gaps, exclusion of double lines, exclusion dangles and offset polylines curves. The Rhino 3D, by its nature CAD, presented many difficulties in the execution of the setbacks of the polylines of the lots, since it could not perform the offset of untrimmed curves, especially when the polylines were composed of parts of lines, arcs and curves that would require topological adjustments, as explained by Liu et al. (2006). However, once identified the problem, a resource was found made available by a user, which demonstrates the advantages of using an application with many users and sharing their studies.

e. Associated database recognition: In CityEngine, by its GIS database, when importing a layer of information it already recognizes the associated information in database tables. Rhino 3D, by its CAD nature, requires the composition of algorithms that will reassemble the database, recognize and display information from the associated tables.

f. The dynamical potential of representation: In CityEngine the generated rules allow the user to perform changes of parameters values and dynamically obtain the visualization of the future landscape resulted from their choices. In Rhino 3D this can also be done, but it is not automatic: it requires the user to program an interface where this interaction with users can happen.

It should be noted that the purpose of the article is not to judge "better" or "worse", but to elucidate differences, limitations and potentialities of the applications, since each one has a part that is very effective.

Regarding innovations, in addition to the generated scripts that can help many other users in their studies, the potential of modeling, simulation and visualization of future Brazilian landscapes resulting from the application of urban planning parameters is highlighted. The most interesting part is to generate different scenarios, both from the parameters in current use, and from possible other values to be decided by participatory planning.

The production of the algorithms is absolutely technical and requires expert knowledge, but the use of the models that were constructed can be done by users who need to conduct a decision-making process on urban land-use laws, such as public authorities and town planners. The people of the place, stakeholders, can count on the dynamic visualization of results as support for their opinion and decision making.

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