

MODELAGEM DINÂMICA DE COMBINAÇÃO DE VARIÁVEIS POR MULTICRITÉRIOS: EMPREGO DE MODELO PARAMÉTRICO E ALGORITMO GENÉTICO NO ESTUDO DA ÁREA DE PATRIMÔNIO MUNDIAL RECONHECIDO PELA UNESCO NA PAMPULHA, BRASIL

Dynamic models of multicriteria to combine variables: the use of parametric model and genetic algorithm in the study of the World Heritage area recognized by UNESCO in Pampulha, Brazil

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ABSTRACT: The present paper surveys dynamic models of multicriteria to combine variables using parametric model and genetic algorithm as a method of changing the adequacy level of variables in a multicriteria analysis (MCA). The aim is to simulate if-then scenarios of territorial occupation of commerce, housing and green areas. The case study is a MCA for the buffer zone of the modern assembly of Niemeyer in Pampulha region, Belo Horizonte, Brazil, declared World Heritage by UNESCO. The parametric model was developed in Grasshopper software. The level of adequacy of the territorial units to characterize attractiveness and vulnerabilities to land use change was defined by “knowledge-driven” in the layers: Safety Risks; Fragility in Infrastructure; Bus Stop; and Centralities due to Interaction Potential. The land use change simulation “if-then” was defined by “objective-driven”. The simulation due the use of fitness-function in genetic algorithm, with the goal to achieve the best distribution of land use changes. The fitness function seeks the results of the use of the territory in a more equitable way, considering the attractiveness and vulnerabilities defined by the characteristics of the neighborhoods (centralities, transportation, security and weaknesses in infrastructure). The parametric model generates “if-then” simulation, changing the land use (commerce, housing or vegetation), which results in new levels of adequacy, and calculates the index of suitability for each territorial unit (the lot) with the best situation to the objective of the fitness-function.

KEYWORDS: Multicriteria analysis; Parametric modeling; Genetic algorithm; Scenario simulation; Objective-driven evaluation.

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INTRODUCTION

An analysis of the urban environment involves the consideration of several variables, which are in constant interaction and transformation. Creating a synthesis of urban analysis implies combining and associating these data. As most of the information concerning the urban context has a spatial element, the urban planning decision-making process requires the analysis of geographic data. Multicriteria Analysis (MCA) is one methodology widely applied to urban studies. As, in solving a complex problem, it can consider multiple variables including geographic data, it is possible to create a summarized integrated model to support the decision-making process.

The MCA requires the definition of several aspects involving the decision context and considering the objective of study. Firstly, it requires the definition of the variables that describe the area, or the scenario, and interfere in the decision context. Also, it requires the classification of the suitability of the area to the objective of study, considering each variable. This may be established in accordance with the current and existing situation or can be composed according to future expectations or scenarios, changing the score or level of suitability of the variables. After that, the MCA combines the level of adequacy of each variable with the defined set of weights, generating the overall value. This final value is called the index of suitability of the territorial unit for the MCA objective (Figure 1).

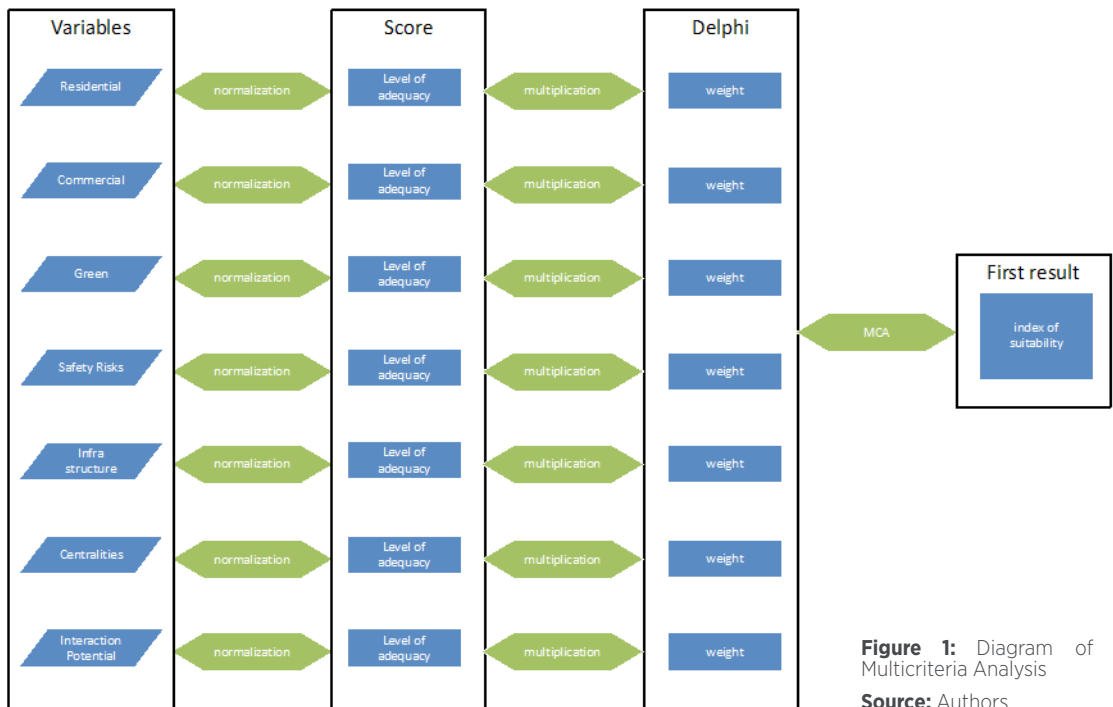


Figure 1: Diagram of a Multicriteria Analysis
Source: Authors.

The paper investigates methods of changing the level of adequacy of the variables in a MCA through parametric modeling. It aims to explore the parametric method called Genetic Algorithm (GA) to alter only the level of adequacy of some variables. The set of weights is maintained and the altered level of adequacy is used to simulate future scenarios that improve the index of suitability of the area (Figure 2). The goal is to find new patterns of occupation that compose the synthesis that will better fit the goal to distribute land use according to the principle of equality and promoting

more distributed good areas. The equality in quality of the place can be an important strategy for urban planning, as it balances the potentials of seeking for the smallest difference between the variables' levels of adequacy, which indicate the index of suitability. The simulation scenario can indicate the best possible way to equilibrate the conditions within the area.

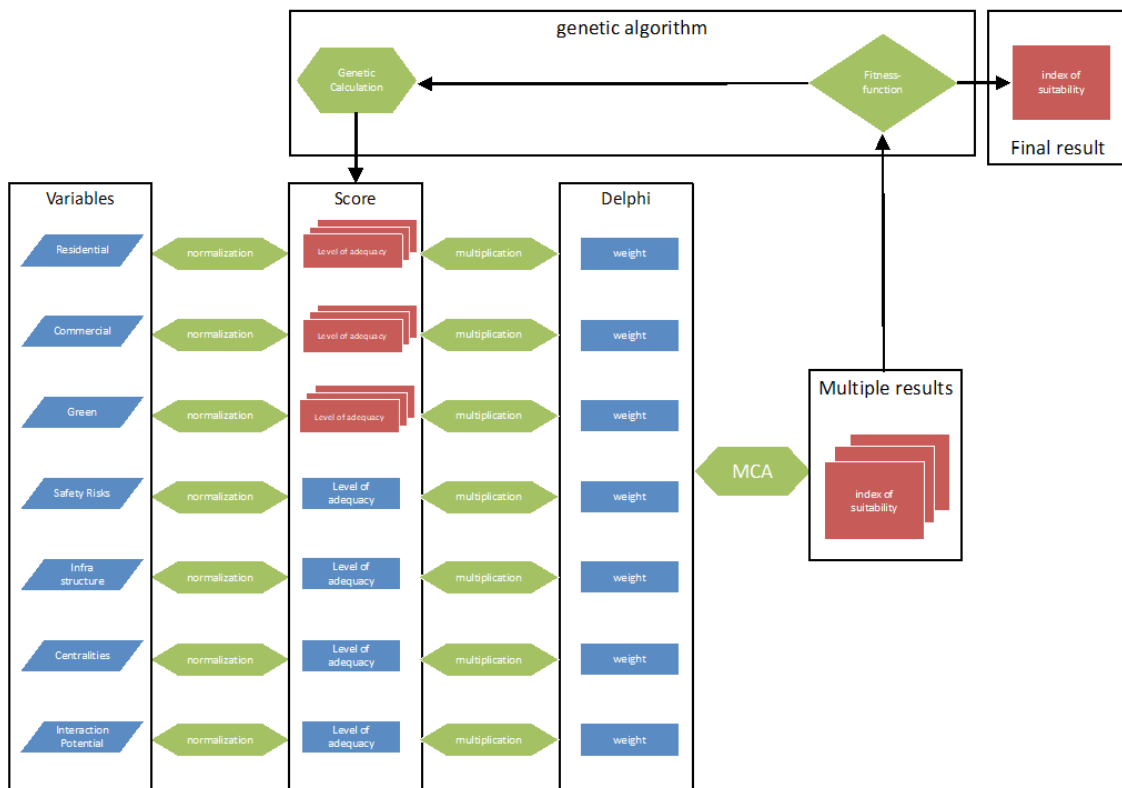


Figure 2: Diagram of the genetic simulation experiment

Source: Authors.

The research axis adopted by the article is to develop an exploratory analysis of the application of spatial models and techniques that perform the process of working with major component variables (decomposing reality into some themes), promoting the integration of these variables (to spatialize attractivities, potentialities or vulnerabilities) and simulate and recompose these variables in probability studies in *If-Then logic*. Being an exploratory study, it has the freedom of experimentation that does not necessarily result in practical applications that can be immediately used in territorial planning. It fulfills the function of awakening possibilities of using logics and mathematical processes, in the form of algorithms, in an initial approach that awakens ideas for new developments and applicability.

Among the models of spatial analysis adopted there is Multicriteria Analysis, which works with the composition of main variables that, integrated, indicate areas suitable for some activity or event, or areas lacking some intervention or transformation. The model is already widely used in studies of spatial analysis, in the sciences that have the territory as support. The article goes one step further and develops a script that makes the combination of variables be performed automatically, by genetic algorithm, in many simulations until an established goal is reached, which would be the best possible result in the combination of those variables. As the study is still exploratory, the goal itself was also arbitrated with the aim of having equitable distribution of some land uses in the territory, among three defined types of use. In future studies the goal may not be an equitable

distribution, but rather favor the development of certain portions of the territory, or even the introduction of a more complex set of variables.

The objective of the article is to explore the potentialities of simulation in a genetic algorithm, using a set of parameters according to parametric modeling, to increase the potentialities of the multicriteria analysis model. If the study was limited to the use of Multicriteria Analysis, the result would be a single scenario as an answer, but with the use of parametric modeling and multiple simulations by genetic algorithm, the application produces a much larger set of responses internally of the application, and chooses among them the one that most suits a previously defined expectation. The resulting scientific contribution is to promote reflection on the possibilities of integrating the chosen models, with gaining information and producing more complex answers, which may favor decisions in the future where there are different perspectives and expectations.

Multicriteria Analysis

The Multicriteria Analysis (MCA) is a decision-making method for complex planning problems involving the identification of main components from a phenomenon or occurrence and the combination of these main variables according to parameters that indicate the importance of each one in the final result. It's based on systemic approach and models, because it presents the idea that you have to decompose reality according to main characteristics, that are the variables, and then compose the elements according to their importance, that are their values or parameters.

As a model, it's a simplification of reality according to main characteristics and can be presented in a logic, a law, a theory, a hypothesis, a structured idea, a relation, a function, an equation or a synthesis of data that represents the real world (HUGGETT, 1980; MOURA, 2009). Recognizing the complexity of reality and avoiding rigid representations, dynamic models are being applied to simulate a set of possibilities instead of just one result. This paper is a study about dynamic models based on parametric modeling.

MCA can be used as a methodology of spatial analysis studies, which combines and associates geographic data of different variables in order to support decision-making (JANKOWSKI & RICHARD, 1994). The first step is the definition of main variables. The second step is the definition of the importance of each variable in the final results, what means the value to be associated to it, the parameter itself. The variables are combined on map algebra, and the results of this combination are based on the relative importance of each criterion. People involved in the process define the relative importance using various methods and techniques (DODGSON, 2009).

The third step is the definition of geographic territorial unit to integrate the variables (lot, block, neighborhood or even a regular grid of spatial positions), according to the objective of analysis. The fourth step is to prepare all the variables (by layers) according to a surface of spatial distribution of it, already classified in scores according to the objective of analysis. In general, the scores need to be standardized for the same measurement unit, in order to be combined (EASTMAN et al., 1995). As an example, if the goal is to investigate areas for urban growth and densification, the distribution of commerce in the area must be transformed into a surface presenting from the areas with lack of units to the concentration of the activities, while the land use must be classified from suitable to not suitable to urban growth, but both variables must have the same initial value and the same final value, what is the normalization of the score. Spatial units (grids, lots, territorial units) and also spatial distribution of characteristics (the scores of the variables) must be normalized to compose a matrix with the same spatial reference and the same score in values, so that the map algebra can be applied.

After all, preparing the four steps, it's time to define the importance of each variable in the map algebra combination (MOURA, 2007). The

MCA result is an index of suitability or vulnerability to the problem or question that was presented. For example, the researcher can investigate the suitability for urban growth and sprawl, suitability for land use change, vulnerability of geotechnical risks, vulnerability for landscape and environmental protection. The result is a spatial ranking from the worst to the best condition, in relative scale, in which each portion from the territory presents a value that is positioned in a hierarchized scale. The user can analyze the results choosing the best places for the future intervention, or even recognizing the classification of the place he had already chosen in order to provide better conditions, as it's possible to understand which were the variables and parameters that interfered in the result. As an example, if he was investigating suitability of urban growth and a specific area of interest was not well classified, he can identify fragilities in variables, (example transportation), and can control if the result changes according to different parameters applied to that variable.

One of the most common procedures in MCA is the weighted linear combination method. According to Eastman et al. (1995), in this method, a weight is multiplied by each variable's level of adequacy and then summed with its value for other variables to get a final index of suitability for each unit. Thus, a suitability map results from the combination of weighted variables. In order to increase the reliability of the process, there are several methodologies for the definition of weights.

There are different methods to define the importance of the variables, and to choose the parameters that represent this importance. According to Bonham-Carter (1994) the definition of parameters, known as the "weight" to the variables in the weighted average that is the most used algorithm applied to map algebra of Multicriteria Analysis, can be defined by "knowledge-driven evaluation" (interviewing experts) or by "data-driven evaluation" (analyzing a set of data and searching for tendencies). But according to Motta, Moura and Ribeiro (2017), there is also the "visual-driven" in which the user can simulate alternative parameters and get the dynamic results from each combination, what is a support to opinion making. In the case study it was applied "knowledge-driven evaluation" based on Delphi method, in which a group of participants give suggestion about the importance of the variables to arrive to an index of suitability in two rounds: a first round declaring anonymously their votes, and after receiving the media of the opinions of the participants they can change or keep their votes, so that the second media is the distribution of the weights (LINSTONE et al., 1975).

In Pampulha case study the goal was suitability of quality of the place, and people were asked about the importance of each variable to provide that index of quality. In the case study, after constructing the first result with the weights in MCA (Figure 01), the genetic algorithm was applied but weights were kept the same, while the values of some variables were changed to search for multiple results and the most suitable result among them (Figure 2).

As a contribution of the paper, the current study presents a fourth possibility to define parameters in MCA, based on the application of algorithms that will search for the best combination of values to achieve a specific condition established by the researcher: the "objective-driven evaluation".

Parametric modeling and genetic algorithm

Parametric modeling is largely used in architecture nowadays to generate new shapes in contemporary projects. It adopts parameters and functions by computing processes that explore the potential of geometric modeling (FLORIO, 2011). Parameters and functions are connected and organized through algorithms to be altered and manipulated in a logical process. In most cases, it creatively explores the mathematical possibilities in an architectural scale but it is still slightly used in an urban scale. In urban planning there are a few groups using parametricism, such as Zaha Hadid

Architects (SCHUMACHER, 2009). Nevertheless, the referred modeling is not so applied in cartography and spatial visualization mechanisms. Instead, it is only used by those who exploit the PPGIS (Planning Participatory GIS) possibilities as a future landscape production mechanism in applications of dynamic cartography and visualization of changes in spatial results (LEACH, 2009); and in the simulation of parameters alterations for production of dynamic cartography by Parametric Modeling in Territorial Occupation and Urban Landscape (MOURA, 2013).

Parametric modeling allows the use of evolutionary computing based on algorithms (genetic algorithms) that embrace Darwinian principles to calculate processes (SIMON, 2013). The genetic algorithm uses the trial and error approach in order to solve a function or a group of functions for numerical optimization (BÄCK, FOGEL & MICHALEWICZ, 1997). The optimization of a function aims to find the best result to problem solving. This is called a fitness function. In fact, this solution is not necessarily exact or determinist, but a heuristic solution for the issue (MICHALEWICZ & FOGEL, 2013).

This approach is suitable in solutions of inaccurate or even impossible problems phenomena. Those problems often have meta-heuristics characteristics and the calculation of the numerical optimization solution gives a group of heuristic possible results, in other words, a group of approximated results to the problem resolution criterion. New populations of individuals/results are generated for potential evolution in problem solving. The decision of the following events to be calculated for the future population works in an undefined way. Once the repeated population defines the best available value, the adequate solution for the problem is concluded.

The Darwinian principles are used for the development of the population results and to determine the behavior of the calculation. The genetic algorithms ascertain, by evolutionary principles, how the parameters are going to interact and how the calculations development will generate, select, evaluate and choose the population of results (HINGSTON, BARONE & MICHALEWICZ, 2008).

Simulation using evolutionary computing has an analysis potential for inaccurate problems. These problems must have a consistent structure with this heuristic nature. It usually uses storage methods in order to develop the calculations. The calculation evolution or even the several attempts to search for an adequate solution for the problem work in a random way. The main purpose is to calculate a population of potential results/individuals to reach the best available solution. The results from the generated population are confronted with the desired solution and identified its level of suitability towards the problem solving. News generations of population are subsequently calculated from the previous generation to find a more possible suitable solution.

METHODS

The research axis adopted by the article is to develop an exploratory analysis of the application of dynamic model for urban studies. For it, the methodology adopted in the research was Design Science Research – DSR (DRESCH, LACERDA, JÚNIOR, 2015; PEFFERS, 2007). The research sought for a solution to the practical problem of the adequate tool to dynamic model of MCA in an urban area. The solution was based on theoretical foundations and aimed to respond to the real case as much as to be adaptable to other cases. The research was developed in 6 steps, as shown by table 1.

Firstly, to define the theoretical basis, the article presents a literature review about MCA and GA concepts. After presenting the investigation of the theoretical knowledge, the parametric model that was developed using Grasshopper software was described.

1. Find a relevant practical problem:	Alterations in the indexes of suitability of the MCA variables
2. Examine the research potential:	Literature review of MCA and GA
3. Obtain theoretical and practical knowledge:	Searching for MCA and GA tools
4. Solution proposal:	Development of a genetic parametric model in Grasshopper
5. Implement and test the solution:	Simulate scenarios in buffer zone in the protected area of Unesco in Pampulha, Brazil
6. Ponder the applicability:	Evaluate the results

Table 1: Research development steps

Source: Authors.

In order to test the model, genetic simulations of future scenarios were performed using the Unesco buffer zone of Pampulha Region, Brazil, as a study area. Finally, the article presents a critical analysis of the observed results.

The research proposes “if-then” simulations, where the methodological model operates hypothetical scenarios of *if* the context changes, *then* the index of suitability become more balanced. The simulations, which are considered as possible future scenarios or contexts, can be made through the modification of the condition of each variable. Therefore, the model operates a variation in the scores among the territorial units in the search for new patterns that are in accordance with the objective proposed by the researchers.

In the case study of this paper the genetic algorithm was planned to achieve a fitness-function so that to simulate alternative futures to a territory, considering local characteristics and opinion from experts about the importance of existing attractiveness and vulnerabilities. It presents the innovation of “objective-driven” evaluation to be applied in Multicriteria Analysis, in order to simulate not only one result but possible different results considering the complexity of reality, visualized in dynamic cartography, but presenting the most feasible result according to the definition of fitness-function. The biggest challenge was the choice of variables and the definition of the fitness-function, so that in future studies it is possible to include a greater number of land use typologies and variables. The most interesting contribution was the “objective-driven” evaluation based on genetic algorithm.

CASE STUDY - PROPOSAL AND RESULTS

The case study is an illustration of the possibilities to apply genetic algorithm based of fitness-function to simulate the alternative futures to a land use change considering the opinion of experts and also the according to a defined objective.

The buffer zone of World Heritage protection recognized by UNESCO in Pampulha, Belo Horizonte

In July 2016 Pampulha, in Belo Horizonte, received the title of World Heritage by UNESCO, due to the exceptionality of the architecture design of Oscar Niemeyer in the urban assembly, composed not only to modern

architecture and its originality and authenticity, but also to the report through architectural, landscape and urban scale. It means that valorization and protection of Niemeyer's work is very important to the World, but also the equilibrium of anthropic and natural values, in the sense of landscape (Figure 03).

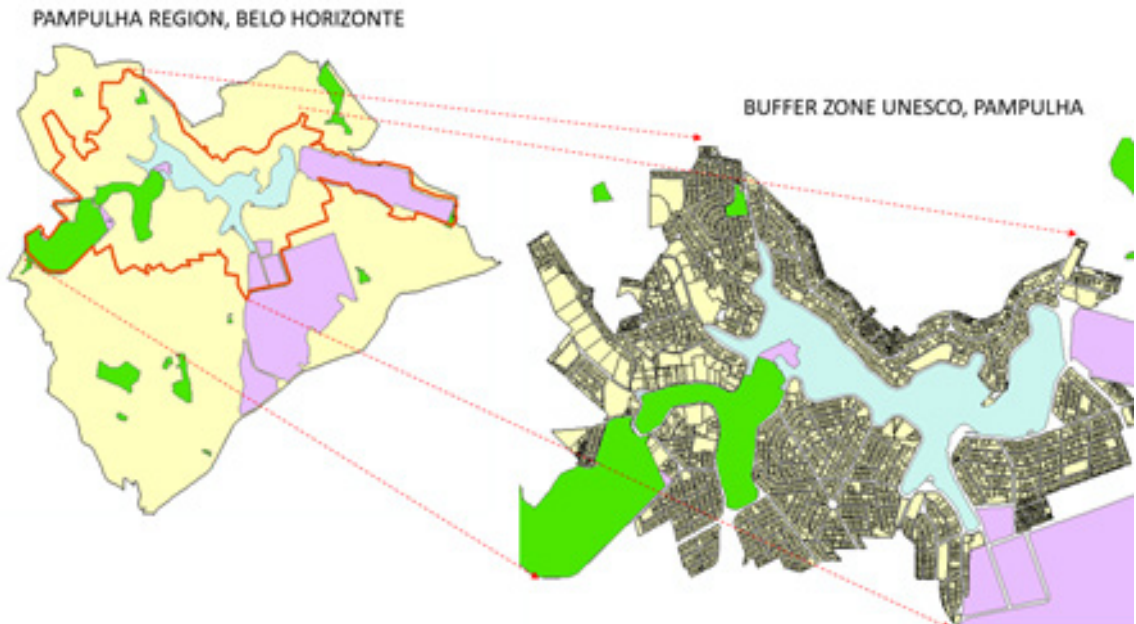


Figure 3: Case study: Buffer Zone UNESCO, Pampulha, Belo Horizonte

Source: Authors.

The protected area defines a buffer zone, composed by the border of the lake and its surroundings. We analyzed this area to understand that it has homogeneity and heterogeneity, what is quite interesting as a case study to simulate alternative futures. The homogeneity comes from the dimension and land use of the lots, most of them big lots around 1000 m², with residential uses characterized by expressive green areas. Pampulha is the region that has the best quality of green in Belo Horizonte and the landscape is characterized by an equilibrium of volumetric buildings and vegetation cover (Rocha et al., 2017).

The heterogeneity comes from the distribution of commerce and services, that are concentrated just in few some centralities and not distributed along the region, resulting in lack of integration potential and places that people meet in daily needs and consumption. There is also heterogeneity due to environmental risks and safety risks. In the border of the lake, in the buffer zone for protection, there are places with sanitation fragilities, in risks of flood and of tropical diseases. The safety risks can be problems to tourism development but also to the development of the area.

Because of spatial homogeneity related to the lots (spatial units) and heterogeneity related to the characteristics (spatial variables) the area was chosen as a case study, because it was possible to calibrate and validate the results. It was just a first experiment to be tested in other case studies, and to be developed in more complex models to represent other spatial analysis.

Multicriteria Analysis tool using Genetic Algorithm

The Multicriteria Analysis tool consists of a parametric model developed in Grasshopper® software using genetic algorithms. The parametric model algorithm considers the following steps (Figure 04).

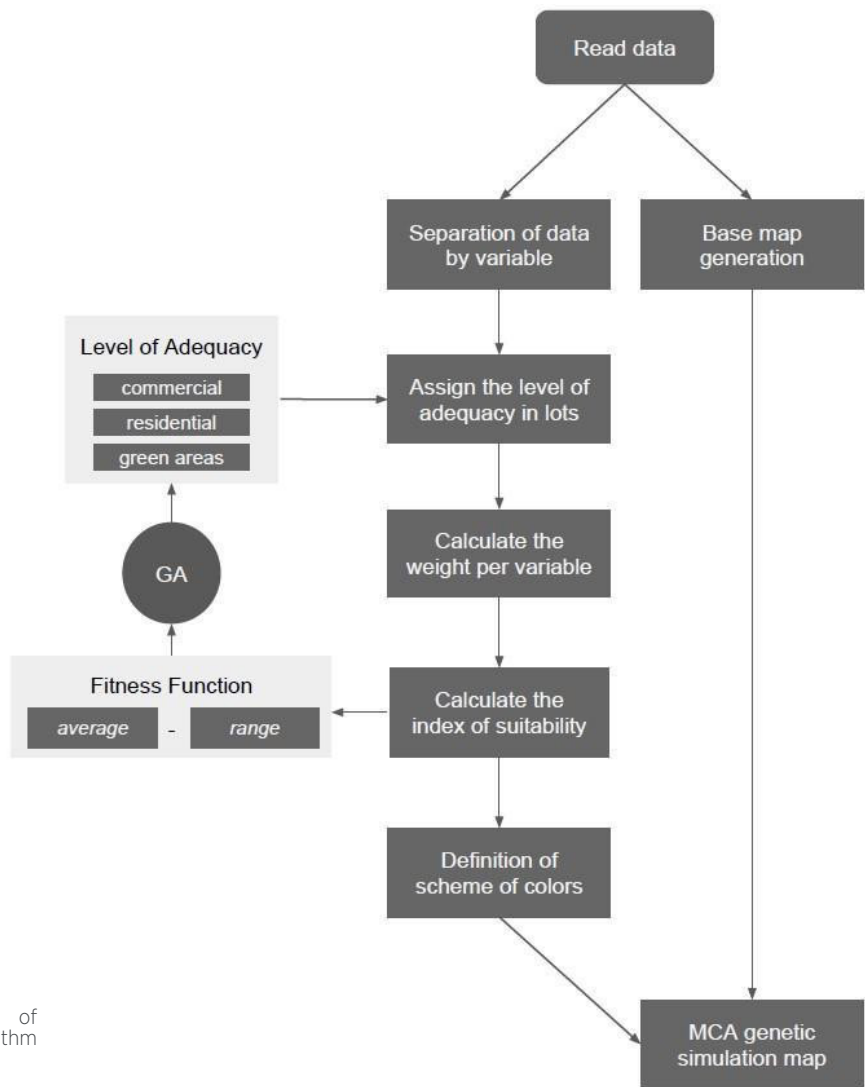


Figure 4: Flowchart of Grasshopper® algorithm steps

Source: Authors.

The Figure 05 shows the algorithm such as viewed in Grasshopper@:

Firstly, the parametric model processes a database by importing a shapefile (*shp*) previously prepared using ArcGis®, with spatial reference in UTM WGS-84 coordinate system. The *shp* was composed by the polygons of lots linked with alphanumeric data presented in table about four variables (safety risks; fragility in infrastructure; bus stop; interaction potential). In each column of the table it was registered the level of adequacy of the variable in the lot. The definition of the level of adequacy of the variable “safety risks” consider the risk of crimes and robberies, using data of the site “*onde fui roubado*” (“where I was robbed”) considering also the proximity of banks, unlit places and places where people concentrates waiting for services as buses. The layer “fragility in infrastructure” presents the indexes of health risk due to the presence of dengue fever, spotted fever, flood and precarious sewage network. The “bus stop” layer consider the proximity of the service. The “interaction potential” layer consider the accessibility and the urban dynamic, as an index of centralities due to concentration of service and commerce combined with roads’ facilities.

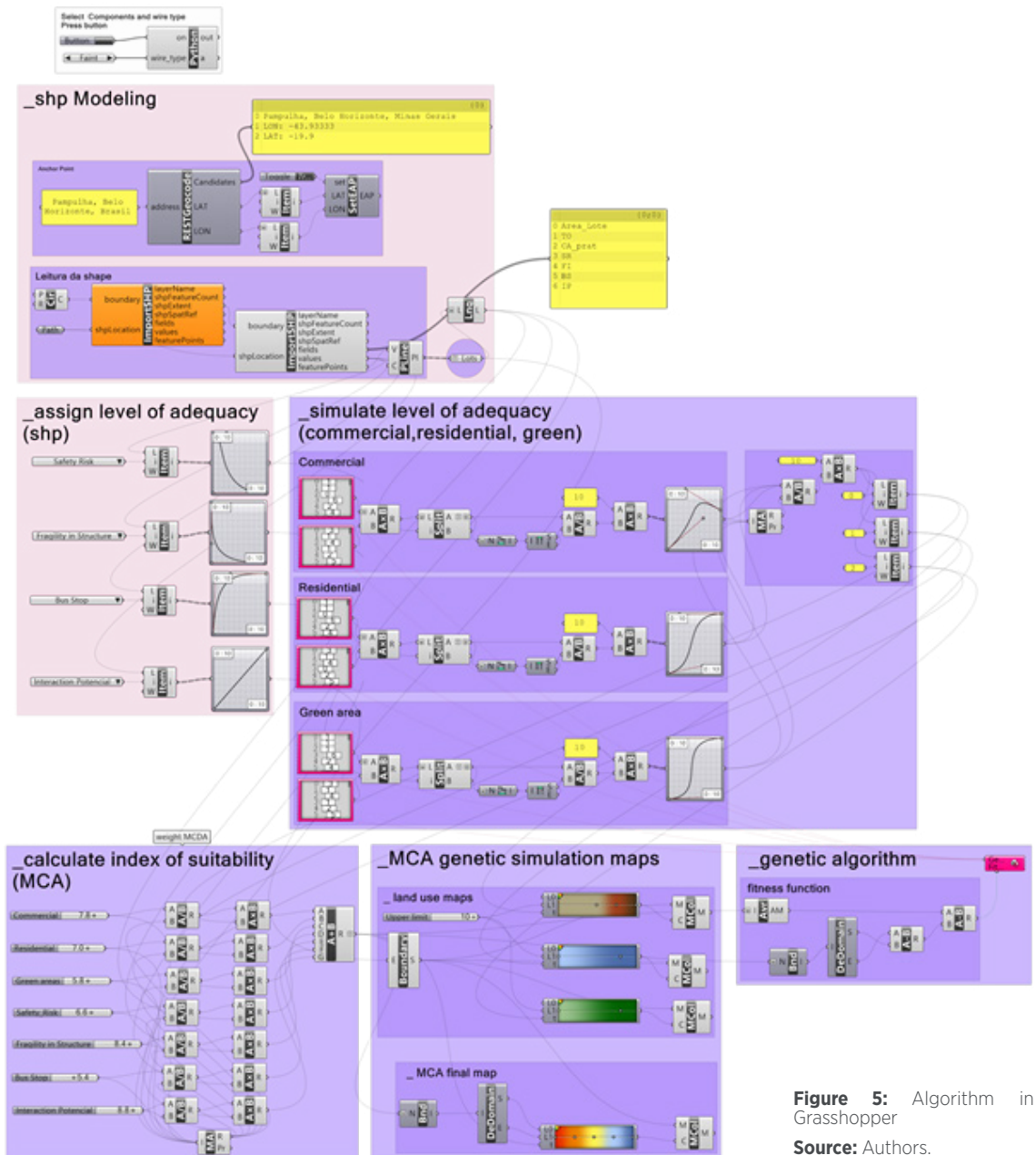


Figure 5: Algorithm in Grasshopper

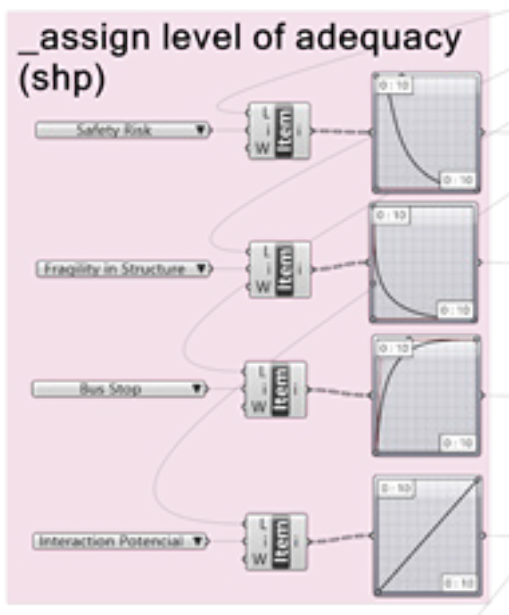
Source: Authors.

After importing the *shp* file, the algorithm separates the levels of adequacy of the four variables individually, those were registered in the table linked to the polygons, and associates them one by one to each geo-referenced lot. According to each variable it was defined a behavior function that better represents the performance of it, representing what happens if the value of the variable increases: does the quality of the place increases proportionately? Is there a value from which the quality doesn't change anymore?

For example: commerce is considered a good condition to the quality of the place, but after a certain level of concentration of this use, the quality declines indicating a saturation of this type of use. The behavior function of this variable can be composed by a curve that simulates it: increasing until at a certain point, and after this limit defined by experts it declines. To each variable, academic experts defined a curve by simple agreement. The figure 06 shows the behavior curves used in each variable.

Figure 6: Behavior functions to Safety Risks, Fragility in Infrastructure, Bus Stop, Interaction Potential

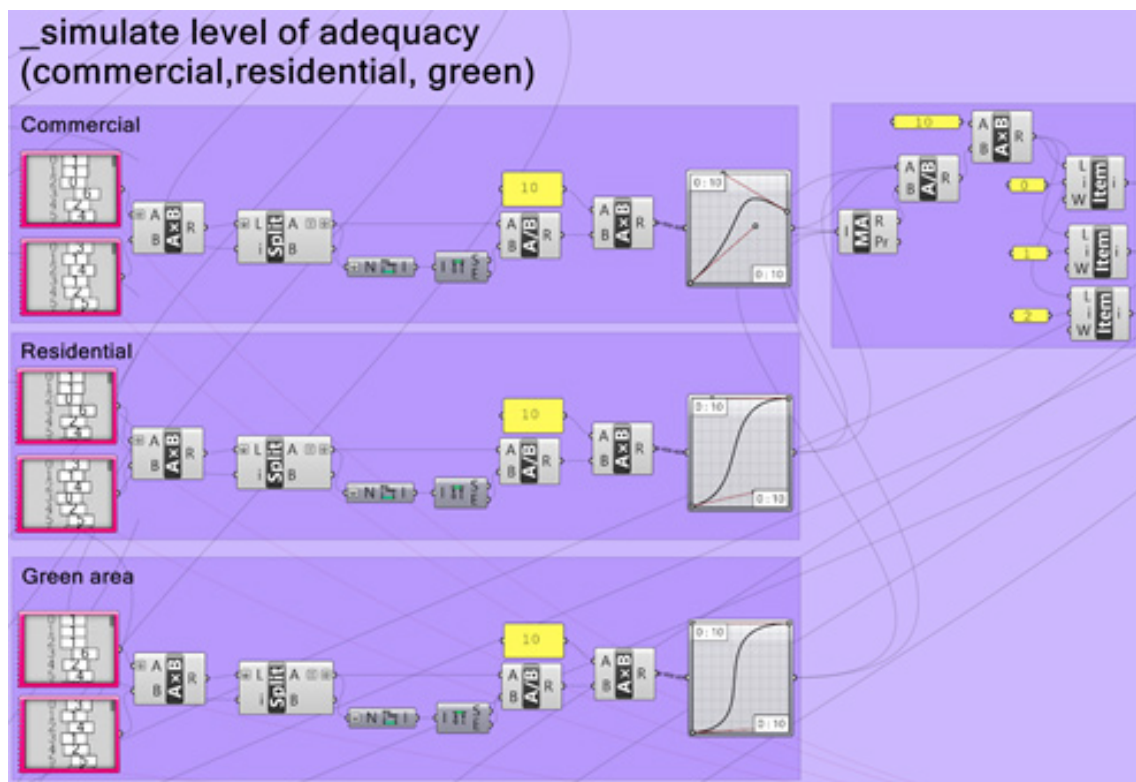
Source: Authors.



The algorithm adds three new layers in the model: Commercial, Residential and Green Areas. The layers were added to simulate the territorial occupation of these uses. It was used a *gen pool* function (group of dynamic sliders) to assign the news scores/level of adequacy in the lots. It was also used a behavior function to adjust the assigned level of adequacy. The figure 07 shows these parts of algorithm.

Figure 7: Assign new layers/ levels of adequacy

Source: Authors.



The algorithm uses the strategy of Dynamic Calculation of MCA weights to the MCA calculation (MOTTA et al., 2017). With the MCA set, it is possible to simulate scenarios of territorial occupation. The simulation of possible scenarios and contexts was made through a genetic function that changes the score/level of adequacy. The land use variables of commercial, residential and green area were used for the if/then simulations of new territorial patterns. The genetic calculation performed the variation of the units' scores/levels of adequacy for each lot, changing the gen pool values in a random way.

Parallel to the dynamic calculation of the *index of suitability*, the algorithm models a map of the area from the geo-referenced points. The territorial unit adopted was the urban lot. A 2D base map of the area was generated to be used as a *map view* of the different aspects such as variables (one by one), synthesis of results, etc.

Afterwards, the dynamic calculation results in an index of suitability, according to spatial units and represented in a ranking of color scheme. For the visualization, a different scheme was adopted for each variable that was altered by the genetic algorithm. The commercial variable was drawn using a brown gradient. The residential variable used a blue gradient. The green areas variable used a green gradient. In these cases, stronger colors indicate higher values. For the final MCA map (index of suitability), a *red to blue* gradient was adopted, in which red indicates low values, yellow indicates medium values and blue indicates high values (Figure 08).

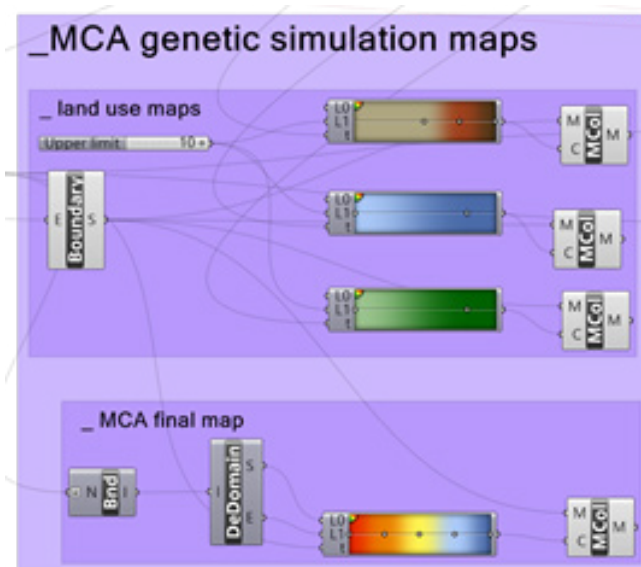


Figure 8: Creating the map view

Source: Authors.

Genetic simulation experiment

In order to simulate scenarios in UNESCO's buffer area of Pampulha, an experiment of MCA was made using the genetic algorithm. Firstly, a set of weights were defined and settled in Grasshopper. The definition of weights was made by knowledge-driven, with the contribution of academic experts through two rounds of Delphi method (LINSTONE et al., 1975) that is a way to achieve consensus maximization in opinions. The objective pursued was to generate an index of suitability for each territorial unit in a way to increase the quality of the place. Table 2 shows the variables and their respective weights resulted from Delphi method and settled in the combination of MCA.

Commercial	7.8
Residential	7.0
Green areas	5.8
Safety Risks	6.6
Infrastructure	8.4
Bus Stop and Centralities	5.4
Interaction Potential	8.8

Table 2: Set of weights
Source: Authors.

Subsequently, the genetic algorithm changes dynamically the level of adequacy of chosen variables: commercial, residential and green areas. For this alteration, we adopted a strategy that the sum of the three variables had to be 10. In that way, any alteration in one variable implies on altering the others. This was made to avoid the overlaps in maximum value of the three variables in territorial occupation of the same lot, but accepting the combination of them in multiple uses.

The alteration of levels of adequacy was made through the manipulation of the sliders in *gen pool*. The values of the levels of adequacy are defined by a simple multiplication of two sets of *gen pool* (Figure 07). Each *gen pool* has one hundred sliders so that the multiplication of two set results in ten thousand values. These values are randomly assigned to the lots, simulating many possibilities of combinations of variables.

The fitness function of the genetic calculation considered two requirements to achieve the suitability results. The first was the average of the values in all lots, to guarantee equality in territorial distribution. The second was the range of all values (difference between maximum and minimum value), to achieve the better condition in the lot. The objective of the fitness function was to find the highest values of *average* combined (best condition) with lower values of *range* (minimum difference among places). For this, the fitness function equation was defined as:

$$\rightarrow (average) - (range)$$

The genetic simulation was performed using an evolutionary solution method. It was produced 49 generations with 99 genome/populations for each one of the 5632 individuals/lots. One mutation was introduced every 10th generation. An increase in the fitness score was observed until the 10th generation. After first mutation, between the 10th and the 20th generation, there was no increase in the results. After second mutation, between 20th and 30th generation, there was a great increase compared with the first mutation, reaching results better than the one from 10th first generation (before first mutation). After third mutation (after 30th generation), the results showed very small increases. In the fourth mutation, after the 40th generation, the results decreased significantly, but in a few generations they again achieved the best results. Figure 09 shows the window during the genetic simulation.

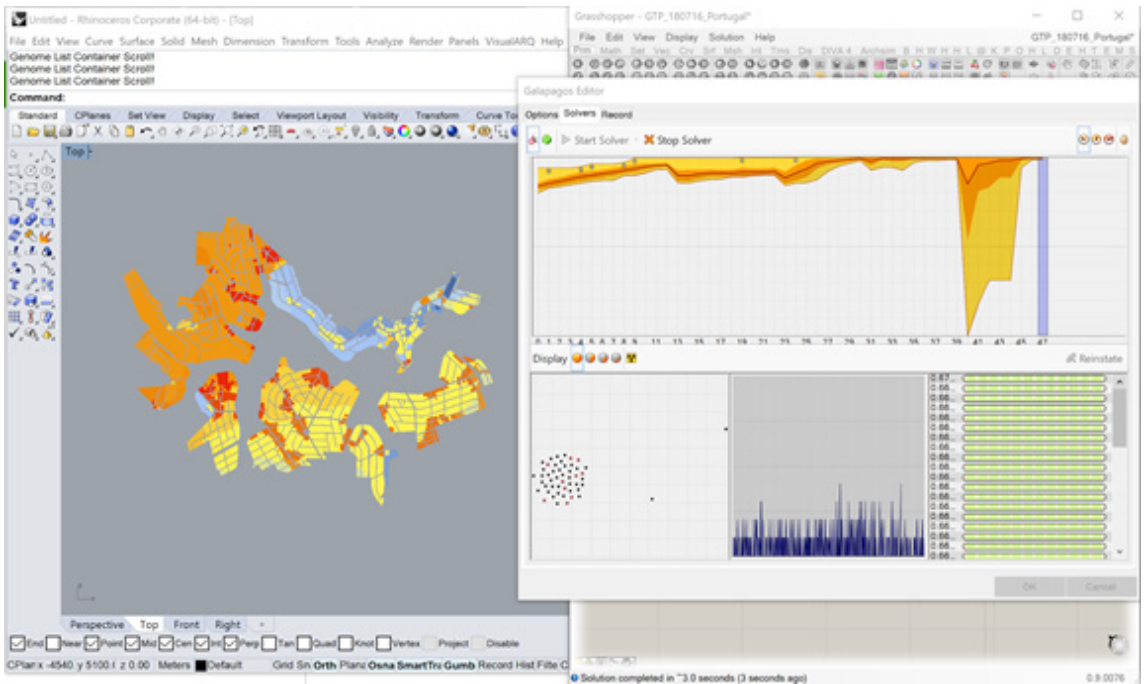


Figure 9: Genetic simulation
Source: Authors.

Figure 10 shows the map before the genetic simulation (a) and the map after genetic simulation (b). The map of Figure 10a considers only the four initial variables/layer: Safe Risk, Fragility in Structure, Bus Stop and Interaction Potential. The map of Figure 10b shows all variables/layers, after simulated Commercial, Residential, and Green area territorial occupation. As it's important to analyze the results with more accuracy, details of the parts that changed most were presented (Figures 11, 12 and 13).



Figure 10: Maps of Unesco's buffer zone: 4 shp layers (a); 7 layers after genetic simulation (b)
Source: Authors.

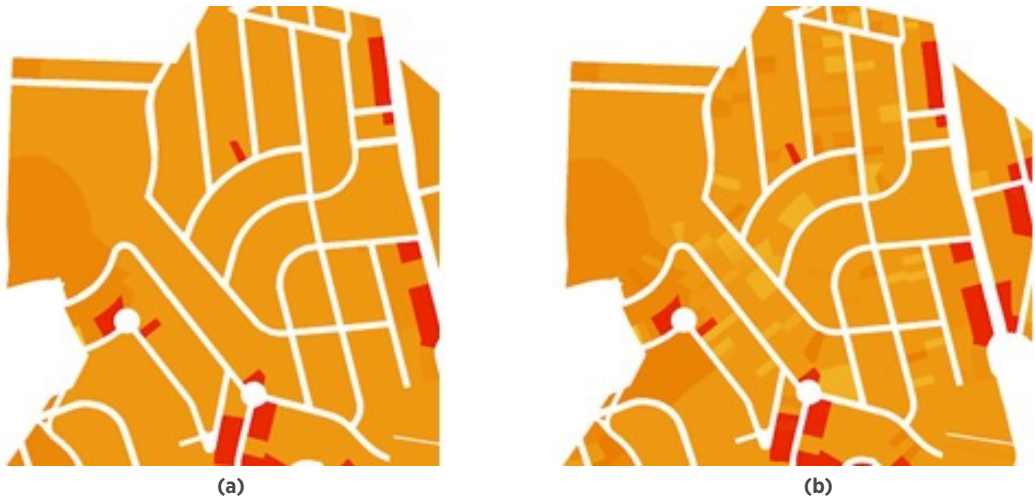


Figure 11: Detail of Northwest area: 4 *shp* layers (a); 7 layers after genetic simulation (b)
Source: Authors.



Figure 12: Detail of North area: 4 *shp* layers (a); 7 layers after genetic simulation (b)
Source: Authors.



Figure 13: Detail of Center area: 4 *shp* layers (a); 7 layers after genetic simulation (b)
Source: Authors.

The genetic experiment indicated similar pattern before and after the simulation. It was observed concentration of changes in individual lots in the West, Northwest, North and Central areas. It is important to remember that the fitness function was intended to equitably distribute the potential transformation in the area, what means that some lots could lose potential in favor of better distribution of resources and to achieve according to the three uses, and it was observed that changes happens in one or two levels in the indexes of suitability and quality of the place. As it was expected, the impact was not enough to meaningful change the index of suitability pattern. This follows what happens in reality, in which land use changes step by step.

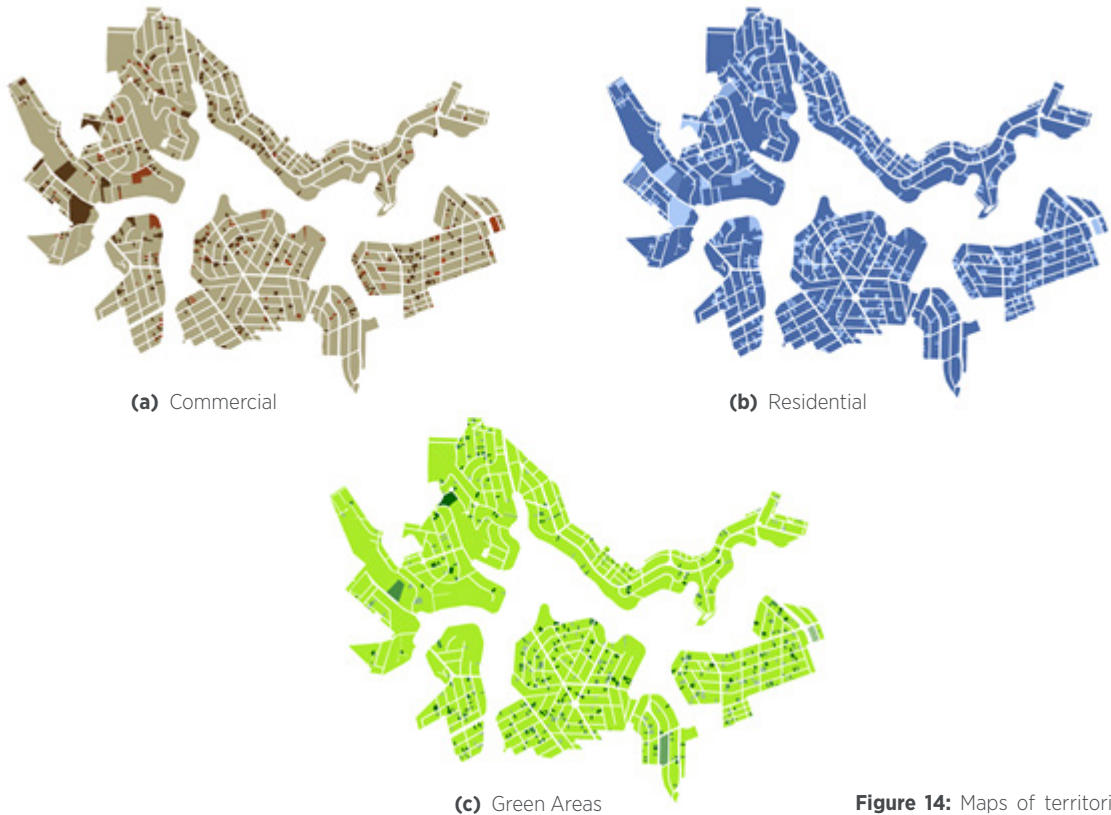


Figure 14: Maps of territorial occupation after genetic simulation

Source: Authors.

It is possible to observe some aspects when analyzing the resulting maps. Firstly, on the Commercial map (Figure 14a), the occurrence of commercial use is concentrated in specific lots/units, mainly located in the west. On Residential maps it is observed the distribution of occupation in all area, with greater intensity than the other uses. On Green Areas map, the occurrence is interspersed and heterogeneous all over the buffer zone, in low intensity.

DISCUSSION AND CONCLUSIONS

The MCA is a traditional and useful method to support the spatial planning process, from the landscape and environmental scale to urban and architectonic scale, as it's quite useful whenever the researcher needs to define suitability and vulnerability, presented as spatial indexes to land changes in projects or policies.

The use of MCA for the “if-then” simulation, presented in this paper

based on “knowledge-driven” but also as “objective-driven” evaluation, has a great potential. The challenges to studies are the methods of changing parameters and methods to calculate synthesis. Changes in the level of adequacy have potential as a good strategy for the “if-then” simulation using MCA. Knowing that, these changes are often a complex calculation, the use of genetic algorithm, based on “fitness function” using genetic methods, indicate potential as methodology approach.

The research evaluated a Grasshopper® algorithm modeled to be the engine of the simulation of different levels of adequacy in a MCA. The experiment demonstrated the ability of the tool for calculating “if-then” simulations. In the experiment, the objective was to simulate land use change based on commerce, housing and vegetation to achieve a spatial equilibrium of land use in order to have not only environmental quality but also urban facilities. The fitness function had to change the distribution of land use (commerce, housing and vegetation) but considering the attractiveness and vulnerabilities defined by the variables. Attractiveness was defined by centralities represented in integration potential that results from accessibility on roads and concentration of commerce and services, also by transportation represented by bus stops. Vulnerabilities were defined by safety risks due to crimes, dark areas and concentration of people on roads; and also vulnerabilities due to lack of urban infrastructure represented by problems of flood, sanitary and sewage fragilities and tropical diseases (dengue and spotted fever - *febre maculosa*).

The objective of this research was to evaluate the applicability of the genetic algorithm based on fitness function in the “if-then” simulation, as a possibility of “objective-driven evaluation” in Multicriteria Analysis. The main issue was to choose the driven variables, the characterization of its performance (behavior function), the set of the weights, and the formulation of the fitness function (objective to be achieved by simulation).

There are limitations of immediate applicability, because it is an exploratory study. It fulfills the task of thinking about the potentialities of associating MCA with PM/GA to obtain answers that result from the comparison of many possibilities and that it is possible to draw the best scenario that best suits a specific objective function. However, for real applicability, it would be necessary to revise the list of variables worked and eventually the defined objective function (in this case equitable distribution of land use). As an exploratory study, it is a first step that awakens to new possibilities, already proving the potentialities of the models used in an integrated way.

There are foreign groups doing simulations of potential land uses by integrating variables, such as Zaha Hadid’s studies on the “Adaptive Urban Fabric” (Kartal MasterPlan, Zaha Hadid Architects, 2006), but for them the simulation predicts installation of uses in unoccupied territories, which function as an ideal surface and those without roughness of an existing occupation. Thus, for Brazilian case studies that do not deal with the sprawl of new occupations, but rather with the search for a balance in land use, new constraints would have to be incorporated so that the study was not a mathematical, numerical and spatial approach.

The experiment presented good results and its use proved to be of great potential. The algorithm was very robust and present the results in short time, what means that further exploration can be added to it, in order to model the complexity of reality. New explorations, considering others variables, new goals and fitness function may be undertaken in future investigations.

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REFERÊNCIAS

- BÄCK, Thomas; FOGEL, David B.; MICHALEWICZ, Zbigniew. **Handbook of evolutionary computation**. CRC Press, 1997.
- BONHAM-CARTER, Graeme F. **Geographic Information Systems for Geoscientists; modelling with GIS**. Ottawa, Pergamon, 1994. 398 p.
- DRESCH, Aline; LACERDA, Daniel Pacheco; JÚNIOR, José Antonio Valle Antunes. **Design science research: método de pesquisa para avanço da ciência e tecnologia**. Bookman Editora, 2015.
- DODGSON, John S. et al. Multi-criteria analysis: a manual. 2009.
- EASTMAN, J. R. et al. Raster procedures for multicriteria/multi-objective decisions. **Photogrammetric Engineering & Remote Sensing**, v. 61, n. 5, p. 539-547, 1995.
- FLORIO, Wilson. Modelagem paramétrica, criatividade e projeto: duas experiências com estudantes de arquitetura. **Gestão & Tecnologia de Projetos**, v. 6, n. 2, p. 43-66, 2012.
- HINGSTON, Philip F.; BARONE, Luigi C.; MICHALEWICZ, Zbigniew (Ed.). **Design by evolution: advances in evolutionary design**. Springer Science & Business Media, 2008.
- HUGGETT, Richard. **Systems analysis in geography; contemporary problems in geography**. Oxford: Clarendon Press, 1980. 208 p.
- JANKOWSKI, Piotr; RICHARD, L. Integration of GIS-based suitability analysis and multicriteria evaluation in a spatial decision support system for route selection. **Environment and Planning B: Planning and Design**, v. 21, n. 3, p. 323-340, 1994.
- LEACH, Neil. Digital cities. **Architectural Design**, v. 79, n. 4, p. 6-13, 2009.
- LINSTONE, Harold A. et al. (Ed.). **The delphi method**. Reading, MA: Addison-Wesley, 1975.
- MICHALEWICZ, Zbigniew; FOGEL, David B. **How to solve it: modern heuristics**. Springer Science & Business Media, 2013.
- MOTTA, Sílvia R.; MOURA, Ana Clara M.; RIBEIRO, Suellen R. Ampliando do *data-driven* e *knowledge-driven* para propor o visual-driven na análise de multicritérios: estudo de caso de modelagem em Grasshopper+Rhino3D. **Revista Brasileira de Cartografia** (2017), Nº 69/8, Edição Especial "Geovisualização, mídias sociais e participação cidadã: apoio à representação, análise e gestão da paisagem": 1456-1475.
- SCHUMACHER, Patrik. Parametricism: A new global style for architecture and urban design. **Architectural Design**, v. 79, n. 4, p. 14-23, 2009.
- SIMON, Dan. **Evolutionary optimization algorithms**. John Wiley & Sons, 2013.
- ZAHA HAHID ARCHITECTS. **Kartal Masterplan**, 2006. Available in: <http://www.zaha-hadid.com/masterplans/kartal-pendik-masterplan/>.
- MOTTA, Sílvia Romero Fonseca; MOURÃO, Ana Clara Moura; GALVÃO, Ana Clara Zandonaidi; RIBEIRO, Suellen Roquete; KATO, Julia Marion Florencio; **Simulation of Scenarios and Urban Analysis Using Parametric Modeling and Genetic Algorithm Based on Multicriteria Analysis**, p. 397-402. In: . São Paulo: Blucher, 2017.
- MOURA, Ana Clara Mourão. Learning topics in urban planning at UFMG: geoprocessing to support analysis, planning and proposal of the urban landscape at neighborhood scale. **Paranoá: cadernos de arquitetura e urbanismo**, n. 7, 2013.
- _____. Aplicação do modelo de polígonos de Voronoi em estudos de áreas de influência de escolas públicas: estudo de caso em Ouro Preto-MG. **Revista Brasileira de Estudos Regionais e Urbanos**, v. 3, n. 2, 2009.
- _____. Reflexões metodológicas como subsídio para estudos ambientais baseados em Análise de Multicritérios. **Simpósio Brasileiro de Sensoriamento Remoto**, v. 13, p. 2899-2906, 2007.
- PEFFERS, Ken et al. A design science research methodology for information systems research. **Journal of management information systems**, v. 24, n. 3, p. 45-77, 2007.
- ROCHA, Nicole A.; SENA, Ítalo S.; CASAGRANDE, Pedro B.; CASTRO, Marina M.; FONSECA, Bráulio M.; MOURA, Ana Clara M. Studies of volumetric relation between vegetation and buildings using LIDAR data and NDVI to propose urban parameters. **Revista Brasileira de Cartografia** (2017), No 69/8, Edição Especial "Geovisualização, mídias sociais e participação cidadã: apoio à representação, análise e gestão da paisagem": 1456-1475.

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