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Editorial correspondence
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"
Piazzale Tecchio, 80
80125 Naples
web: www.tema.unina.it
e-mail: redazione.tema@unina.it

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MOBILITY: EXPLORATORY ANALYSIS FOR TERRITORIAL PREFERENCES

Alessandra G.T. Santos[a], Ana Clara M. Moura[b]

[a] School of Architecture, Federal University of Minas Gerais.
e-mail: alessandragtsantos@gmail.com
URL: http://www.arq.ufmg.br/site/v2/
ORCID: http://orcid.org/0000-0001-6823-1938

[b] Geoprocessing Laboratory, Federal University of Minas Gerais.
e-mail: anaclara@ufmg.br
URL: http://geoproea.arq.ufmg.br/

ABSTRACT

Urban mobility is a current challenge on modern life and has its implications not only on time misuse but also on citizens' health. Spending hours of a day on traffic, people interact with the environment they are susceptible to, which implicates on their manner of seeing, enjoying and living a city. To analyze this impact, an exploratory study was developed on the possibilities of using data composition and spatial analysis tools to select and combine main variables in order to diagnose characteristics of urban landscape on Pampulha Region, in Belo Horizonte (MG), Brazil. Territorial Analysis Units (UTA) were delimited and urban data were studied. First, the main characteristics were represented in categories of variables, and then they were recombined by utilizing Multi-Criteria Methods based on Weighted Sum to present results of suitability for walkability. For each step of spatial analysis, were generated Suitability (Multi-Criteria) and Sensitivity (Uncertainties) Evaluation Maps, proving the similarities of areas considered attractive and vulnerable with the goal to refine the partial results and select the main variables related to walkability. The case study presents the most significant characteristics that might be considered when planning quality of life on urban environments.

KEYWORDS:
Multi-criteria Method; Sensitivity Analysis to Suitability Evaluation; Urban Mobility; Urban Landscape; Pampulha Region

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出行
地域偏好的探索性分析

Alessandra G.T. Santos[a], Ana Clara M. Moura[b]

[a] School of Architecture, Federal University of Minas Gerais.
e-mail: alessandragtsantos@gmail.com
URL: http://www.arq.ufmg.br/site/v2/
ORCID: http://orcid.org/0000-0001-6823-1938

[b] Geoprocessing Laboratory, Federal University of Minas Gerais.
e-mail: anaclara@ufmg.br
URL: http://geoproea.arq.ufmg.br/

摘要

城市出行是现代生活中我们面临的一个挑战，其影响不仅涉及到时间的浪费，同时也对人们的健康不利。人们每天在交通上花费数小时的时间；他们与居身于其中的环境互动，环境对人们对城市的感知、体验和居住方式也产生影响。以分析这种影响为目的，我们开展了一项探索性研究，探讨使用数据和空间分析工具对主要变量进行选择及组合、以便于判定巴西贝洛哈里桑塔（MG）潘普利亚地区城市景观的特点的可能性。其中，对地域分析单位（UTA）进行了界定，并对城市数据进行了研究。首先，将各种主要特征以不同类别的变量表示出来，然后利用多准则方法、根据加权总将其重新组合，以表示步行适宜性结果。空间分析的每个步骤均会生成适宜性（多准则）和敏感性（不确定性）的评价地图，证明被认为有吸引力和易受伤害的不同地区之间存在相似之处，旨在对空间结果进行修正完善，并选择与步行适宜性有关的主要变量。案例研究提供了在规划城市环境中生活质量时可能纳入考虑的最显著特征。

关键词:
多准则方法；适宜性评估的灵敏度分析；城市出行；城市景观；潘普利亚地区

1 INTRODUCTION

Urban daily life requires attention to citizen's demands and urban infrastructure available to them. Urban transportation plays an important role when analyzing how much time citizens spend on their everyday life routes. Time spent to go to and to come back from work or school and to do other activities often represents a significant part of the day, and this is an even bigger problem in countries with lack of organized and well distributed public transportation. These facts call attention to how the itinerary influences human health physically, mentally, and emotionally. Issues related to mobility must consider not only the difficulties in daily life as vulnerabilities, but also the quality of the place where people circulate on, because this may be seen as attractiveness and potentiality to urban planning, providing better places and routes to citizens' circulation.

Aiming to comprehend conscious and/or unconscious interactions between citizens and urban landscape and its consequences, the research organized data and produced information about existing infrastructure and visual landscape perception of a case study, using geoprocessing and computing tools. The main objectives were to identify characteristics and phenomena that may configure a landscape as attractive or not for citizens, in the sense of topophilia or topophobia, meaning how people feel about places (Tuan, 1974); and to parameterize its conditions in order to recognize areas which present similar aspects, but are not categorized as attractive and its probable reasons.

The study area chosen was the Pampulha Region (IMG.1), located in the northwest of Belo Horizonte (BH), capital of Minas Gerais state, Brazil. The region has an area of 47 square km, 34 districts and 10 slums, with a population of 187,315 inhabitants and a density of 40.13 inhab./km (IBGE, 2010), characterized by an expressive amount of remaining vegetation coverage that represents 26 km² of the area. Its choice was based on its natural, social and infrastructural characteristics, besides its data availability for the Laboratory of Geoprocessing's researchers due to an agreement with the City Hall.

It is the main destination for open air activities within BH; it is mostly flat and presents relatively low density and traffic jams – distinctively from most parts of the city and favorable for active transportation. Moreover, it is known for tourism activities and recognized by UNESCO as a World Heritage Centre, but still has a mixed land use with diversely residential, commercial, industrial, and institutional areas. In addition, transportation's phenomena occur in Pampulha, configuring interesting challenges to be studied: mobility islands caused by large landmarks as the Pampulha Lake, the Federal University of Minas Gerais (UFMG), the Governador Magalhães Pinto Stadium (Mineirão), the Pampulha Airport, and the BH Zoo; and underexplored walkability, despite its infrastructure and favorable conditions to walk compared to other regions of the city.

2 METHODOLOGY

Aiming to approach distinct methodologies of analyzing the area of study, the research has been developed applying two methodologies whose results will be compared on further studies. The first one, entitled Urban Resources (UR), is based on the main spatial characteristics of the Region and will be the focus of this paper. The second one, entitled Citizens' Perception (CP), considers citizens' opinions about their preferences on walking through the landscape in the Region and will be explained on a future paper.

Studies about the characterization of the area, according to Urban Resources, require the definition of a territorial reference to collect and analyze the data. The chosen method was the Territorial Analysis Units (UTA) that allows the comparison between distinct areas of the Pampulha Region. They were delimited in 5144 UTAs, approximately 1 per lane of road added with a buffer of 15 meters inside lots to capture vegetation or characteristics that are on the front part of the lot and are seen by the walker, composing the landscape. The territorial units were constructed using Voronoi polygons, calculating the area of influence of each track considering the road plus the frontal part of the lots, the first 15 meters.

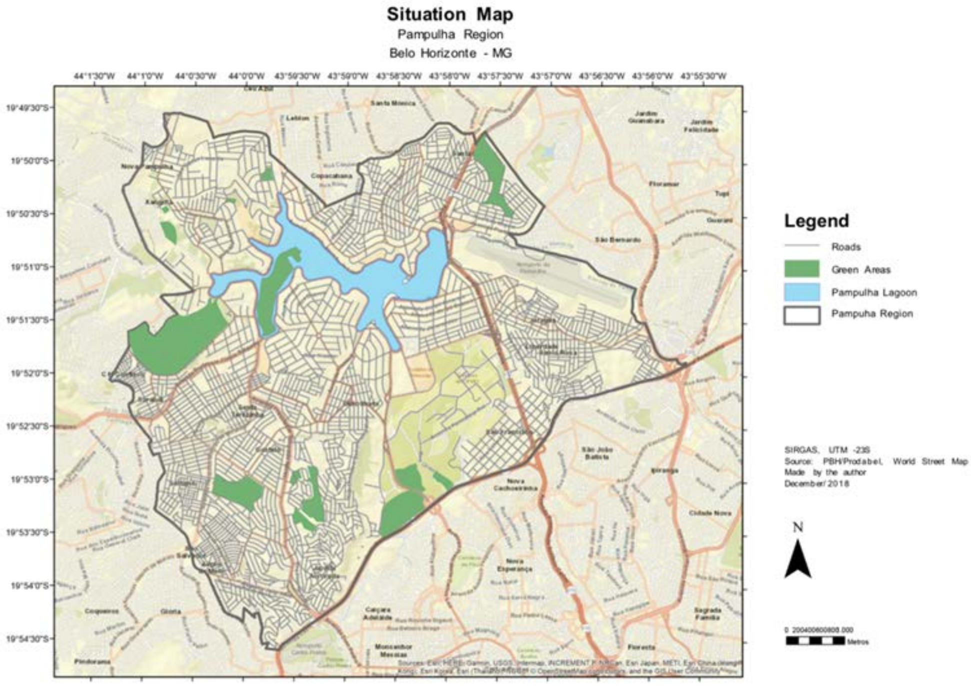

Fig. 1 Pampulha Region Situation Map

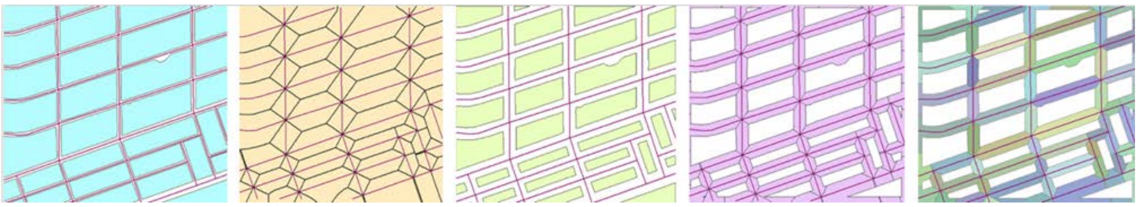

Fig. 2 UTAs construction: from roads and blocks to Voronoi polygons, resulting in one polygon per track

The second step was to define the main variables to be organized, using data provided by the City Hall or producing data by geoprocessing methods. The goal was to decompose reality according to its main characteristics, to compose the variables in principles of spatial analysis to represent the territorial distribution of occurrences or phenomena, and to recompose groups of variables to configure portraits of spatial reality. The method is based on suitability evaluation and studies about uncertainty in the results (Moura, 2007).

The process was oriented by the first part of Geodesign Framework developed by Steinitz (2012), and by studies of uncertainty developed by Ligmann-Zielinska and Jankowski (2012, 2014) according to the methods proposed by Moura and Jankowski (2016), consisting on data assessment based on:

- analyzing data and building Representation Models;
- manipulating information and building Process Models;
- applying knowledge and building Evaluation Models;
- analyzing results and calculating levels of uncertainty on the model.

Thus, the first step was to design Representation Models based on the urban data collected. This data was available due to an agreement, Urban Information Management Group (GGIU), between The Laboratory of Geoprocessing and The City Hall of Belo Horizonte (PBH/Prodabel). To design the Representation Models, a process of structuring and organization of urban infrastructure and environmental data was developed, as listed on the Results section, Tab. 1. Secondly, from these Representation Models and for the Process Models step, 30 (thirty) product files and 19 (nineteen) process-maps were generated, cited on Tab. 1.

Thirdly, to build Evaluation Models, two types of multi-criteria analysis were applied: the Multi-Criteria tool from the ArcGIS software and the Monte Carlo Weighted Sum evaluation tool (Jankowski & Ligmann-Zielinska, 2012, 2014; Moura & Jankowski, 2016). On the first method, all variables had the same weight equal to 5.26, calculated dividing 100 per 19 variables, producing a multi-criteria analysis map.

For the Monte Carlo analysis, the model increases the possibilities of weights to each variable, applying random values in a range defined by the user. Instead of just calculating one result, the model simulates many possible values of weights inside a minimum and a maximum value and compares the results in the many scenarios simulated. In those parts in which the results changed more according to changes in weights randomly selected in a defined range, it is possible to say that the level of uncertainty is higher. Using the tools developed by Jankowski and Ligmann-Zielinska (2014), two maps were produced: an evaluation map, as a suitability map for walkability in the territory, resulted from equal weight values for all variables, and an analysis of uncertainty of the results. Using the Multi-Criteria evaluation method, the Suitability Analysis Map was produced, and using the Monte Carlo method to calculate the uncertainty, the Sensitivity Evaluation Map was generated.

The process categorized each variable as high suitability and low sensitivity, or high suitability and high sensitivity, or low suitability and low sensitivity or low suitability and high sensitivity. The aim was to find results with high suitability and low sensitivity or, at least, high suitability and high sensitivity.

The application used enabled the identification of the most robust variables analysed and the variables that were more related to the level of uncertainty. In this sense, it was possible to identify and eliminate three variables, and to construct a new suitability map using the Multi-Criteria method. They were:

- residence's concentration: it is due to a peculiar characteristic of Pampulha Region that, for example, regions with low density could be great or terrible for walking. It increased the uncertainty levels of this variable;
- roads' Hierarchy: it is a technical nomenclature used by the City Hall that not necessarily represents a road's dimension but it is used to define authorization for land uses, and it was irrelevant for the proposed analysis;
- quantity of Bus Lines: Belo Horizonte's bus system (BRT/MOVE) works with few bus lines riding on main avenues that connect users to transfer stations. Therefore, it shows an inconsistent data comparing main avenues (with few lines but regular services) and ordinary roads (with more lines but not so regular services).

On second round, the Multi-Criteria evaluation tool was applied using only the 16 variables that had robust results. It also generated a Suitability Evaluation Map (based on multi-criteria analysis) and a Sensitivity Evaluation Map (based on Monte Carlo uncertainty analysis).

A third round of the research was also constructed to consider citizens' opinions on multi-criteria analysis. Instead of using same weights to all variables combined, a Delphi Method was applied to take into consideration people's opinion on the importance of each variable, so weights could represent the hierarchy of preferences on walkability. According to the method presented by Dalkey and Helmer (1963) and Moura (2006), 15 volunteers were interviewed, in anonymous schedule, in two rounds: first, they answered a value that express their opinion about the importance of each variable and the average of each one of them was calculated; then, the first average results were presented to them so they could review their votes, for a final average to be calculated and used as final weights on the multi-criteria combination of variables (Tab. 1).

3 RESULTS

To present the results, a comparison table was built (Tab. 1). On the first columns are listed all urban variables used and their correlated process-maps (the transformation of data into information to characterize occurrences and phenomena). The following columns show each methodology applied, variables weights (WT) used, and, when applicable, its numeric results. The maps generated for each step of Multi-Criteria Analysis Methods are presented on Image 2.

The first step was composed by the calculation of MCA (Multi-Criteria Analysis) using ArcGis tools, considering all 19 variables and applying equal weights to them (5.263%). Since the following step used the same values of the first, but applied on a more qualified methodology - because variables' weights were calculated on a range instead of one unique value –, maps for the first step were not generated due to its lack of robustness.

On the second step, MCA was constructed using Monte Carlo Weighted Sum (Jankowski & Ligmann-Zielinska, 2012, 2014), considering to all 19 variables the same weight of 5,263%, but enlarging the possible weights that were automatically calculated by the tool within a range. As all the variables received the averaged weight, the tool based on the Monte Carlo simulation randomly selected weights within the range of 3,26 to 7,26%, because it represents the standard deviation calculated according to the function of probability density (Moura & Jankowski, 2016).

Along with MCA, the tool calculated the uncertainty based on the variance of the behavior of each variable. The result was that the variables "Bus Lines' Quantity", "Residence's Concentration", and "Roads' Hierarchy" presented the highest variance, which means that their spatial distribution changes a lot in areas that are classified as attractive or vulnerable in the combination of all variables, so they might not be used on further steps. As a result of the second step, those variables were eliminated from the list. The results are on Image 2's first line, maps *a* and *b*, about MCA (Suitability) and Uncertainly (Sensitivity).

The third step was to calculate MCA based on the Monte Carlo simulation again, after eliminating the 3 variables previously cited. The average of weight used was 6.25%, so the tool simulated random possible weights inside the range from 4.25 to 8.25 (according to standard deviation based on function of probability density). Along with the Monte Carlo simulation, the variance composition of variables was calculated, to check if there was still a variable that did not have a robust performance on the integration of all of them, meaning that they changed a lot in areas classified as attractive or vulnerable. As a result, we could observe that all variables were quite robust, and could be kept in the analysis. Only the variable "Concentration of Commerce" had a bigger value, but was still in the limits of robust behavior. The results can be seen on the second line of Image 2, maps *c* and *d*, about MCA (Suitability) and Uncertainly (Sensitivity).

The fourth step had the intention to know people's expectations, on a Delphi Method. Instead of applying the same weight to all variables, the goal was to use the weights according to the citizens' opinions, so that the most important characteristics of the place received higher values.

The interviews with volunteers resulted in values from 1 to 10 to define the importance of the variable (in absolute range), and these values were transformed in relative ones in order to compose a sum of 100%. Using these new values, another integration on MCA was composed, using the Monte Carlo simulation in a range of 2 points less and 2 more based on the value defined by the Delphi analysis. The decomposition of variance was also calculated to check if any variable did not have a robust behavior in the analysis, meaning that they changed a lot on those areas of attractiveness and vulnerabilities produced from the integration of all variables.

As a result, the variable "Permeability Percentage" presented a high variability, which indicated that it could, if reasonable, be further excluded from the list. The results can be seen in maps *e* and *f*, about MCA (Suitability) and Uncertainly (Sensitivity).

Comparing the steps and maps, it is possible to perceive that the analysis acquires refinement by selecting variables that are more related to the quality of urban spaces and walkability. But it is also important to recognize that all maps are very similar, without conflicts of results. It was important to follow all the steps, because the goal was to construct and control the results, improving the analysis, and presenting it as a learning process to researchers, avoiding the "black box" that are quite common in papers.

The quality of results was improved with the partial analysis on each step. In future studies, some of these steps can be eliminated, as we had already understood the partial and final results.

Urban Data	Process Maps	MCA - ArcGIS		MCA - Monte Carlo Weighted Sun + Uncertainty – SASE – 1st round			MCA - Monte Carlo Weighted Sun + Uncertainty – SASE – 2nd round			MCA - Delphi Method			MCA - Monte Carlo Weighted Sun + Uncertainty – SASE – 3rd round		
		Data	WT	Data	WT Range	Variance	Data	WT Range	Variance	Data	WT Absolute	WT Relative	Data	WT Range	Variance
Bus stops	Map of Bus Stops' Concentration	Bus Stops' Concentration	5,26	Bus Stops' Concentration	3,26 to 7,26	-0.065	Bus Stops' Concentra-tion	4,25 to 8,25	0.196	Bus Stops' Concentration	7,8	6,0%	Bus Stops' Concentration	4 to 8	-0.001
Cycle grid	Map of Cycle Grid	Cycle Grid	5,26	Cycle Grid	3,26 to 7,26	-0.127	Cycle Grid	4,25 to 8,25	-0.03	Cycle Grid	8,0	6,1%	Cycle Grid	4,1 to 8,1	0.005
Green areas, urban parks and preservation areas	Map of Permeability Percentage	Permeability Percentage	5,26	Permeability Percentage	3,26 to 7,26	0.125	Permeabil-ity Percentage	4,25 to 8,25	-0.049	Permeability Percentage	9,1	6,9%	Permeability Percentage	4,9 to 8,9	**0.421**
Land densification and building's height	Map of Building's Height Predominance	Building's Height Predominance	5,26	Building's Height Predominance	3,26 to 7,26	0.072	Building's Height Predom-inance	4,25 to 8,25	-0.06	Building's Height Predominance	7,0	5,4%	Building's Height Predominance	3,4 to 7,4	0.003
	Map of Building's Height Variability	Building's Height Variability	5,26	Building's Height Variability	3,26 to 7,26	0.139	Building's Height Variability	4,25 to 8,25	0.106	Building's Height Variability	5,1	4,0%	Building's Height Variability	2 to 6	0.04
Lots' limits, block contours and land use	Map of Commerce Concentration	Commerce Concentration	5,26	Commerce Concentration	3,26 to 7,26	-0.073	Commerce Concentra-tion	4,25 to 8,25	**0.275**	Commerce Concentration	7,0	5,4%	Commerce Concentration	3,4 to 7,4	0.002
	Map of Industry Concentration	Industry Concentration	5,26	Industry Concentration	3,26 to 7,26	-0.133	Industry Concentra-tion	4,25 to 8,25	0.068	Industry Concentration	8,7	6,7%	Industry Concentration	4,7 to 8,7	0.001
Public and private equipment for leisure and tourism	Map of Cultural Attractions' Concentration	Cultural Attractions' Concentration	5,26	Cultural Attractions' Concentration	3,26 to 7,26	0.021	Cultural Attractions' Concentra-tion	4,25 to 8,25	0.013	Cultural Attractions' Concentration	8,4	6,4%	Cultural Attractions' Concentration	4,4 to 8,I4	0.005
Public and private urban equipment for health and education	Map of Urban Equipment Concentration	Urban Equipment Concentration	5,26	Urban Equipment Concentration	3,26 to 7,26	-0.00	Urban Equipment Concentra-tion	4,25 to 8,25	0.05	Urban Equipment Concentration	7,5	5,8%	Urban Equipment Concentration	3,8 to 7,8	0.003
Roads' grid, hierarchy, type, width and pavement	Map of Roads' Width	Roads' Width	5,26	Roads' Width	3,26 to 7,26	0.172	Roads' Width	4,25 to 8,25	0.116	Roads' Width	9,3	7,1%	Roads' Width	5,1 to 9,1	0.011
	Map of Roads' Type	Roads' Type	5,26	Roads' Type	3,26 to 7,26	0.121	Roads' Type	4,25 to 8,25	0.008	Roads' Type	8,6	6,6%	Roads' Type	4,6 to 8,6	0.004
	Map of Roads' Paving Type	Roads' Paving Type	5,26	Roads' Paving Type	3,26 to 7,26	0.054	Roads' Paving Type	4,25 to 8,25	0.061	Roads' Paving Type	8,4	6,4%	Roads' Paving Type	4,4 to 8,4	0.093
Topography and roads' grid	Map of Roads' Slope	Roads' Slope	5,26	Roads' Slope	3,26 to 7,26	0.212	Roads' Slope	4,25 to 8,25	0.061	Roads' Slope	8,7	6,7%	Roads' Slope	4,7 to 8,7	0.054
Trees along the roads and in the frontal part of the lots (seen by walkers)	Map of Tree Concentration	Tree Concentration	5,26	Tree Concentration	3,26 to 7,26	-0.038	Tree Concentra-tion	4,25 to 8,25	0.024	Tree Concentration	9,4	7,2%	Tree Concentration	5,2 to 9,2	0.295
Waterbodies	Map of Waterbodies' Visibility	Waterbodies' Visibility	5,26	Waterbodies' Visibility	3,26 to 7,26	-0.018	Waterbod-ies' Visibility	4,25 to 8,25	0.008	Waterbodies' Visibility	8,5	6,5%	Waterbodies' Visibility	4,5 to 8,5	0.005
Roads' connection and urban services or commerce	Map of Potential Interaction of Urban Nodes	Potential Interaction of Urban Nodes	5,26	Potential Interaction of Urban Nodes	3,26 to 7,26	0.132	Potential Interaction of Urban Nodes	4,25 to 8,25	0.131	Potential Interaction of Urban Nodes	8,8	6,8%	Potential Interaction of Urban Nodes		0.054
Bus lines	Map of Bus Lines' Quantity	Bus Lines' Quantity	5,26	Bus Lines' Quantity	3,26 to 7,26	**0.366**	x	x	x	x	x	x	x	x	x
Lots' limits, block contours and land use	Map of Residence Concentration	Residence Concentration	5,26	Residence Concentration	3,26 to 7,26	**0.411**	x	x	x	x	x	x	x	x	x
Roads' grid, hierarchy, type, width and pavement	Map of Roads' Hierarchy	Roads' Hierarchy	5,26	Roads' Hierarchy	3,26 to 7,26	**-0.367**	x	x	x	x	x	x	x	x	x

Tab. 1 Comparative use of urban data, products generated and results obtained

4 DISCUSSION

When we compare the maps produced, it is possible to understand that the models indicate the same regions as attractive areas and as vulnerable ones. This means that what is recognized as the best region for walkability in terms of technical approach (the first list of variables composed with equal weights) is also the best region in a MCA study with more robust results and going deeper on defining the best variables eliminating those that do not have a behavior that follow the others. The significant difference between the first and the last results is the quality of details and selection of main variables and conditions. Many researchers finish their tasks on the first step, presenting their opinions about the main variables and the final results. Others go further and try to simulate technical opinion but also citizens' way of thinking, constructing different methods of selecting variables and their weights, which can be done by visual driven, data driven or knowledge driven evaluations (Motta et. al, 2017; Moura, 2007; Moura et al., 2018). But the contribution of this paper is to include Sensitivity Analysis in order to recognize which variables really interfere on final results of an integration of values, and to eliminate those that the researcher believes have some importance, but on the case study, they behave in a robust distribution of conditions.

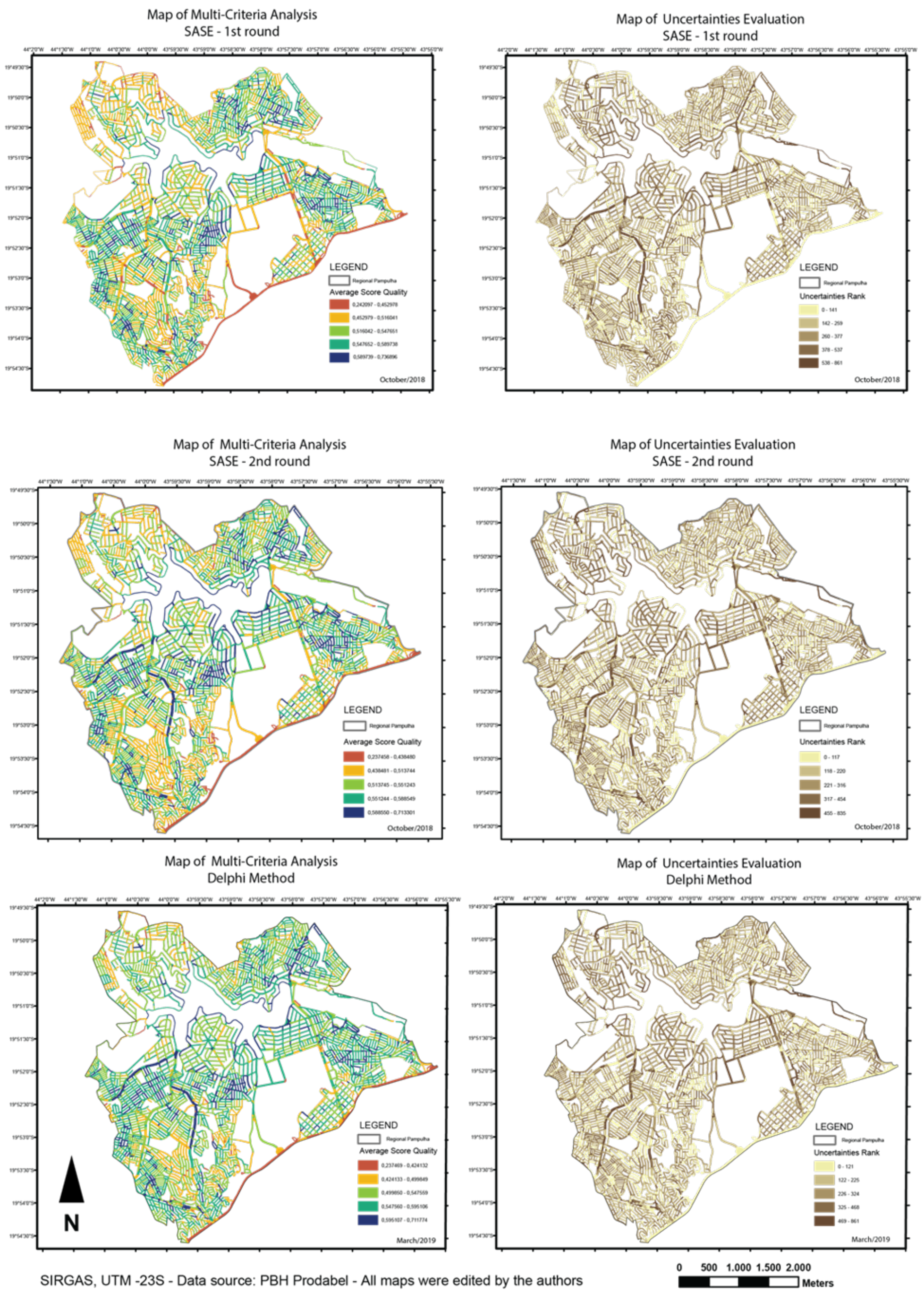

Fig. 3 Multi-Criteria (Suitability) and Uncertainty (Sensitivity) Evaluation Maps

The paper is a step further on multi-criteria analysis, utilizing the SASE methodology (Sensitivity Analysis to Suitability Evaluation) proposed by Ligmann-Zielinska and Jankowski (2012, 2014), with the goal to reduce the initial group of variables to a group of main variables, and also to spatialize uncertainty, to allow researchers to identify places where variables were not the way they expected it to be due to the variation of values. Using this model, it is possible to recognize areas in which there are the most certain attractiveness, areas with questionable attractiveness, and the researcher must go deeper on investigation; areas of certain vulnerabilities, or areas with questionable vulnerabilities that require further studies. The main product of the research so far is the method to go deeper on investigations and to produce steps of spatial analysis that represent knowledge driven (the way experts think) evaluation, to represent citizens' opinion and to compare them with the goal to achieve a first integration of analysis. It is a reproducible and defensible study that has as an output a more qualified spatial analysis. Once this portrait of reality is constructed, it will be time to compare the results with the methods of CP, organized on web-based interview, with the goal to recognize the main characteristics people elected when they classify a place as presenting good quality of urban landscape and as suitable for walkability. This study is under development. Comparing the results of this step with previous ones, it will be possible to recognize the main variables that really relate to urban quality, and this can be considered on urban and landscape management and planning. Studies like these can be a support to the construction of opinion making, and also to decision making, as people can recognize the main characteristics that promote walkability in an area. The identification of conditions is a way to recognize the best places in the city, but mainly a method to select the main variables that can really interfere in quality of urban walkability and must be considered on plans to qualify places and services on urban areas. It has also a goal to encourage people to think about their common problems, values, and expectations.

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AUTHOR'S PROFILE

Alessandra Guimarães. Teixeira Santos, undergraduate student in Architecture and Urbanism on The Federal University of Minas Gerais. Developing a graduation final project on the areas of geoprocessing and computing.

Ana Clara Mourão Moura, graduated from Federal University of Minas Gerais (UFMG), in Architecture and Urbanism (1988), Specialized in Territorial and Urban Planning from PUC-MG and University of Bologna (1990), Master in Geography (Human Organization of Space) from UFMG (1993) and PhD in Geography from Federal University of Rio de Janeiro (2002). She is currently a Professor at UFMG, Department of Urban Planning, School of Architecture, and coordinates the Geoprocessing Laboratory. Coordinator of CNPq (National Council for Scientific and Technological Development) research group: "Geoprocessing in the management of the urban landscape and environment analysis."