Applying Geodesign in Urban Planning Case Study of Pampulha, Belo Horizonte, Brazil

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Abstract. This paper discusses the results of an early case of the application of the concept of Geodesign in Brazil. Geodesign is a new multidisciplinary approach to spatial planning and design that is characterized by the use of GIS methods and tools. In this study, the Geodesign approach is applied – focusing on its analytical part - in two neighborhoods in Pampulha, Belo Horizonte, Brazil, aiming at evaluating their urban quality. The case study was chosen for the integrated capability of balancing urban transformation and preservation of environmental characteristics of the area. In order to evaluate their evolution dynamics a novelty multi-criteria analytical approach was applied to explore which implications spatial phenomena have on the urban quality level and transformation risk in the area. The results of the study highlight the role of knowledge as an essential starting point for urban interventions, in order to inform the design by the specific characteristics of the area and the needs of the citizens.

Keywords: Geodesign, Pampulha, Brazilian Modernism, landscape

1. Introduction

Strong development pressure affects urban areas in many countries worldwide. Design is often guided by economic factors and implemented without taking into proper consideration the local, social and environmental contexts. The risk arises of unsustainable form of urban sprawl which can seriously undermine the achievement of acceptable levels of urban quality. Therefore investments in methodological procedures, capability, and technological bases are needed in order to address its great potential for transformation through sustainable development processes. Capability refers to a collaborative process that can be deployed and through which individual

potentials can be exploited. For this reason, Geodesign represents an interesting alternative and methodological approach to involve different actors - from technicians to stakeholders - in an open and participatory process that enables high visibility of the various actions and responsibilities.

The essence of the Geodesign concept is not new: it is present implicitly in the organic architecture of Frank Lloyd Wright (1867-1959) and more explicitly in the book "Design with Nature" by Ian McHarg (1969). Geodesign is design with the territory and for the territory and it aims at contextualized transformation of the landscape, respecting natural and cultural conditions (Miller 2012).

The concept of Geodesign, therefore, has its roots in more than a century of disciplinary evolution, but nowadays, it gets renewed interest internationally through methods and tools of Geographic Information Science and Technology (Goodchild, 2010). Steinitz (2012) recently proposed an integrated Geodesign framework (GDF) for the development of spatial planning studies, which can be applied at several scales, from the regional to the local one. The framework proposes an integrated collaborative and participatory approach which is based on the application of six models: from the analysis of the context and its internal dynamics, through the development of design alternatives, simulation and evaluation of their impacts, up until the decision making phase in a process strongly linked to the use of Geographic Information Science methods and tools. In this context, Geodesign may provide a systematic methodological framework for regional and urban planning aiming at sustainable integration of human activities with natural environment, respecting cultural peculiarities, and enabling a process of democratic decision making.

Previous studies by Faria and Moura (2014) and Teixeira and Moura (2014) show that specifically the neighborhoods of São Luiz and São José, in Pampulha, which are significant examples of the urban development during the modernist movement in Belo Horizonte in 1940's, have enormous potential in combining areas with environmental and cultural conservation and development attractiveness due to the excellent infrastructures and location. Therefore, in the light of the concepts and practice of Geodesign, this study aims at understanding the processes that describe and explain the condition of a sort of "implicit geodesign" which was observed in this area.

The administrative region of Pampulha is located in the municipality of Belo Horizonte (Figure 1) and it is characterized by complex conflicting interests pertaining both development and landscape preservation.
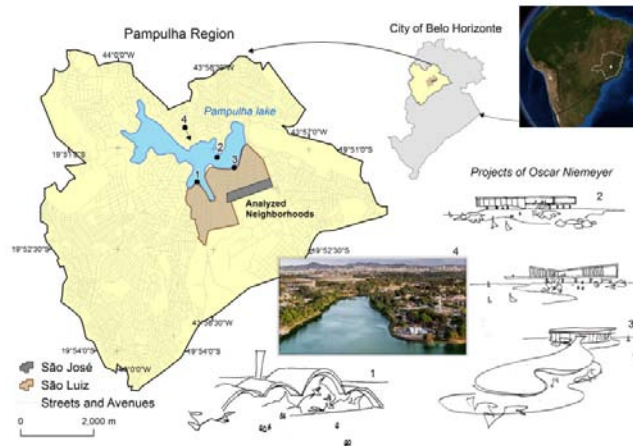
Figure 1. Localization of the study area in the context of Pampulha region and principal projects of the architectural complex designed by Oscar Niemeyer.

The region presents excellent urban infrastructure and services, and still it features a landscape not affected by excessive vertical or volumetric occupation (Faria and Moura, 2014; Teixeira and Moura, 2014). The name of "Pampulha" is commonly associated more with the immediate edge of the lake, rather than with the entire administrative region. The area usually perceived as Pampulha also includes the Museum of Art (located in the former Casino) and the Bandeirantes neighborhood.

Along time, the landscape of the neighborhoods of São Luiz and São José was not substantially altered. For São Luiz the municipal Master Plan established a low-density zoning, and it was declared an *Area de Diretrizes Especiais* (area of special guidelines). The same kind of protection was applied in other zoning districts of the region; however, in the latter, it did not result in such protection of the original urban landscape as in the chosen area. Therefore, it is possible to say that it was not a legal issue that protected the landscape, but rather the values and the uses intrinsic in its characteristics. For this reason, it is important to understand the factors which determinate the *genius loci* (Norberg-Schulz, 1979) of this place, and it is worth investigating its components and key processes.

Conversely, São José was affected by different urban regulations that allowed higher densities, being surrounded by important connecting avenues and large shopping centers. Hence, it suffered more for the impact of densification. Despite its landscape is different from São Luiz, this neighborhood has been included as object of analysis for its position, as well as for the intention to compare different realities in the same territory. The landscape of both neighborhoods is characterized by an interesting environmental and anthropic balance. It can be said that, in its essence, the area is a practical

example of Geodesign, since it supports a balanced territorial occupation, with clearly anthropized area, but it still keeps a strong environmental and cultural character. The relationship between environmental and anthropic elements is of great value, hence it should be preserved and protected.

1.1. The Pampulha Region

As Carsalade (2007) noticed the history of the Pampulha district started with the creation of the artificial lake at the beginning of the 1940s, under the prefecture of Juscelino Kubitschek, who chose Pampulha as flagship development strategy for his government. His idea of transformation concerned at the same time the development of the area as place of residence and as a main tourist and leisure hub for the city. The project aimed to make the region more balanced and socially accessible by everyone in the metropolis, and to protect it from the continuous sprawl of the perverse effects of high density urbanization. Pampulha, along its evolution, shows the double face of urban development and modernization: they were also the seeds of its own environmental degradation and segregation. Its history, therefore, is in itself a synthesis of metropolitan issues of social inequality, irregular occupations, conurbation, environmental problems, but it is also a story of beauty and profound cultural meaning for Belo Horizonte. In Pampulha struggles and celebrations are hidden: the man struggles to create his spaces and the celebration of beauty that comes from the dialogue that man does with nature (Carsalade, 2007).

Pampulha can be considered as one of the earliest example of a genuine Brazilian modernist movement, especially at the urban scale. Starting from the common approach to all modern movements, Oscar Niemeyer broke with the hitherto consensual understanding of architectural rationalism and demonstrated new practice possibilities with a close connection between architecture, structure and references to local languages (Cavalcanti, 2006). However, according to Cavalcanti (2006) Pampulha can be considered the starting place of both the new architectural language, with the projects of the architectural complex by Oscar Niemeyer, and a new type of expansion and urban organization very attentive to environmental quality. As a matter of fact, at that time people were unsure whether to move or not to live in the area. However, slowly Pampulha marked his time and became a trendy spot. In these places it was possible to breathe modernity, the new times, the *esprit nouveau*. The regulations reinforced the urban residential single-family estates in the lakefront, while they were less strict with the preservation in the most peripheral neighborhoods. It is important to understand the impact of this distinction of land occupation when looking at the differences between the São Luiz and São José neighborhoods. Thus, under the stewardship of environmental preservation with highly restricted use and

occupation, the neighborhoods around the lake reinforced the urban enclave of large lots with high value, differing from those prevailing in the north axe of the urban expansion characterized by low-income dwellings.

Given the peculiarities of the region, in this study the concept and the methodological approach of Geodesign were used to understand the processes influencing the urban quality level in order to develop a thorough investigation of the actual conditions and to evaluate the transformation potential of the particular urban context.

2. Methodological framework

The methodological approach of this work is an application of the structure proposed of the Geodesign Framework by Steinitz (2012). It focuses on the answer to six questions about the study area based on six guiding models (Figure 2).
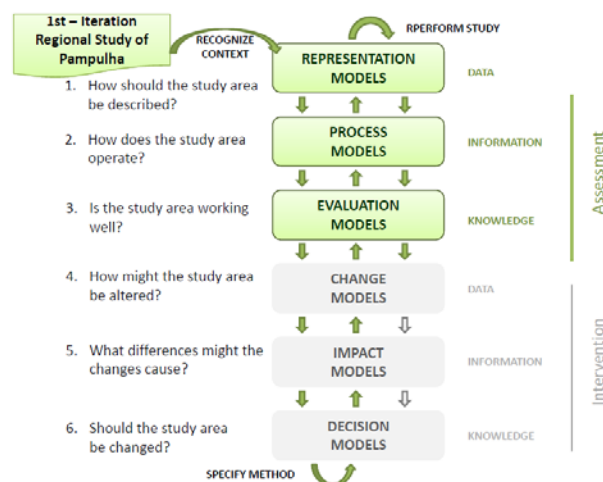

Figure 2. Application of the framework for Geodesign (Steinitz,2012) to the case study.

The first three models include the "assessment process", examining the current conditions, and their possible evolutions, in a particular geographic context. The last three models include the "intervention process", focusing on how the context could be changed, the potential consequences of these changes, and if the context should be changed (Miller, 2012). This process is performed along three iterations: the first one seeks to understand the scope of the analysis and with regards to the case study it is based on the studies made by Faira and Moura (2014) and Teixeira and Moura (2014), that pointed out the main urban phenomena that characterize the study area; in the second iteration, in the light of the objectives, methods and

technologies of the analysis process are defined. Finally, in the third itera-
tion, we performed the analytical procedures, starting with the representa-
tion, Process and Evaluation Models that are discussed in the following
paragraph: 2.1, 2.2 and 2.3 respectively. The results of the analysis are ex-
pected to play an important role in the design of alternative scenarios for
future development in the area, which are, however, beyond the scope of
this paper.

2.1. Representation Model

The neighborhoods of São Luiz and São José correspond to a representative
part of the Pampulha region, particularly in relation to features that charac-
terize the region as a tourist attraction and as an area with the best envi-
ronmental quality in the City of Belo Horizonte (Faira and Moura, 2014). In
the Representation Model the study area is described into a set of digital
data. Data listed in Table 1, which were used to represent, describe, under-
stand and evaluate the processes involved in the study area, were selected
by the research team within the spatial database of the Municipality
(*Companhia de Processamento de Dados* – PRODABEL).

Representation Model (layers)	Data source
Electric Power Pole (points)	GEMINI Project, CEMIG
Building projects recently approved (points)	Period 2009-2013, PRODABEL
Territorial boundaries of the neighborhoods (polygons)	1:5000, PRODABEL
Urban plots (polygons)	1:5000, PRODABEL
Buildings (polygons)	1:5000, PRODABEL
Streets and avenues (polylines)	1:5000, PRODABEL
Contours (polylines)	1:5000, PRODABEL
Laser Scanner cloud of points with attributes of DEM	Period 2009, PRODABEL
Satellite image	RapidEye 2013, resolution 5 m

Table 1. Case study data sources for the Representation Model.

2.2. Process Model

The processes analyzed and considered in this work were identified by a
group of experts of the Geoprocessing Laboratory (GeoLab) in the Federal
University of Minas Gerais (Universidade Federal de Minas Gerais –
UFMG) and divided between processes that characterize current urban
quality conditions and processes that increase the risk of new transfor-
mations in the study area, the latter are seen as factors altering the level of
urban quality. The information collected into the set of digital spatial data
layers in the Representation Model, were combined to describe how the
above spatial phenomena evolve over time influencing the urban quality
and the risk of transformation in the Process Model.

2.2.1. Processes characterizing urban quality

The following list of criteria was chosen to represent the main processes responsible for urban quality, in a clearly anthropized area:

a - **Occupation Density**: it was calculated by applying the kernel density function to the points of electric power poles, weighted by the amount of connections and filtering the residential units only. This means that an attribute measures the number of households served by each point, and the density is captured by these values. Smaller values are assumed to represent higher urban quality;

b - **Volumetric Density**: it was calculated as the ratio between the built volume and the area of the lot. The volume was calculated by multiplying the building area for its average height, which was obtained extracting the majority of the point values of the DEM, by subtracting the DTM surface, and considering only the tops of buildings as in Ribas et al (2014). The greater the density index, the worst could be the effect on urban quality;

c - **Vegetation Cover**: the amount of green areas was calculated by mapping the existing expressive vegetation fragments with automatic classification of RapidEye image composition RGB543. Green areas represent a fundamental parameter in determining the urban quality level of a neighborhood;

d - **Insolation**: it was calculated as the potential impact of solar radiation on buildings wh/m² (Solar Radiation algorithm - ESRI ArcGIS 10.2), which is assumed to influence activities and habits of citizens.

In an area characterized by a high potential of transformation, urban planning and design priorities need to ensure the proper balance between environmental and cultural conditions and urban development.

2.2.2. Processes increasing the risk of transformations

In order to evaluate urban quality, it is necessary to recognize the elements that reduce its level increasing the risk of transformation. In this paragraph, three processes are indicated, which have been identified as major risk factors in the Pampulha case study:

a - **Vehicles Concentration**: the number of vehicles per lane was calculated by the kernel density function applied to the polyline vector dataset, representing the axis of streets and avenues, weighted by the number of vehicles traveling in each direction stored as attribute. This criterion is assumed to influence the perception of security;

b - **Approved Projects**: the concentration of approved projects by the municipal government in the last four years was calculated by the kernel density function applied to the point vector dataset of new approved pro-

jects. These interventions assumed to act as 'attractors' for urban transformation by directing economic interests and influencing decision-making processes;

c - **Trade Concentration**: the concentration of commercial establishments and services was calculated by applying the kernel density function to the points of electric power poles weighted by the amount of connections to buildings with commercial or service use. This data is used as an indicator of the potential transformation level of the area.

With regards to the territorial context, these processes are already underway and can directly affect the future development. The overall Process Model is shown in the analytical model shown in figure 3.
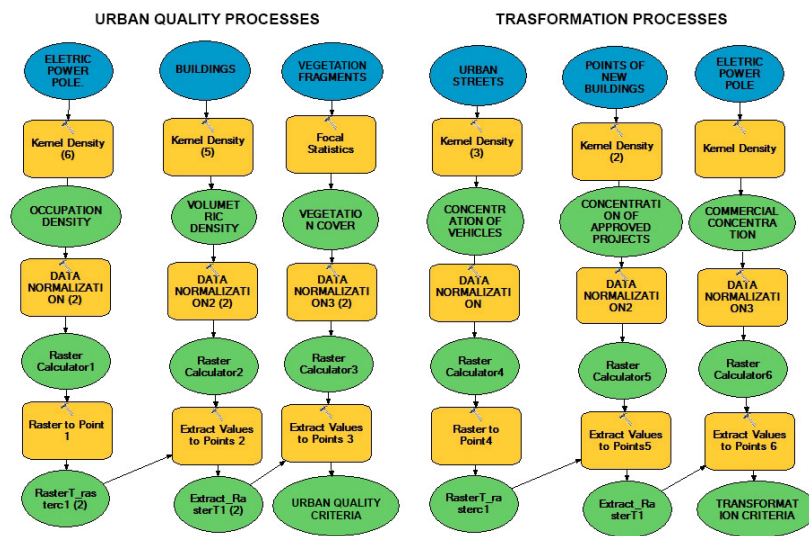
Figure 3. Process Models in ESRI ArcGIS's Model Builder. Ellipses represent datasets, while rectangles represent processing functions.

2.3. Evaluation Model

The Evaluation Model allows exploring how the processes analyzed affect the territorial context and it consists of two analytical models. The first one identifies areas most in need of maintaining urban quality and cultural heritage, while the second one identifies the areas with higher risk of transformation and change in current conditions. Both analytical models were based on Spatial Multi-Criteria Analysis techniques (S-MCA) (Malczewski, 1999), coupled by the Uncertainty and Sensitivity Analysis (USA) (Ligmann-Zielinska and Jankowski, 2008) of the results (Figure 4).
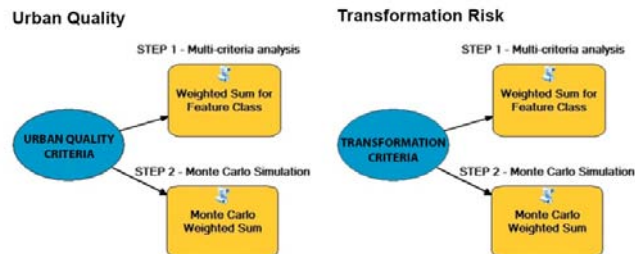
Figure 4. Evaluation Model: Spatial Multi-Criteria Analysis, Uncertainty Analysis.

The S-MCA was based on the assignment of weights to each criteria, chosen by a simplified Delphi (Moura, Jankowski and Cocco 2014) answered by the study team members. The weights assigned in a multi-criteria analysis are often the parameters that provide more subjectivity to the process, directly interfering in assessment and consequently in decision making (Ligmann-Zielinska and Jankowski, 2012, 2014). Therefore, the USA method is applied in order to investigate the weights variability and ensure robustness to the model outcomes. The weights obtained through the simplified Delphi were:

1 – S-MCA to assess the need for maintaining urban quality. This analysis considered the processes that characterize current environmental conditions: Occupation Density with weight 28% (max. 31, min.25); Volumetric Density 37% (max. 40, min.34); and Vegetation Cover 35% (max. 38, min.32).

2 – S-MCA to assess the risk of transformation of the study area. This analysis considered the processes responsible for transformation, which are: Vehicle Concentration with weight 36% (max. 38, min.34); Approved Projects 32 % (max. 47, min.17); and the Trade Concentration 32% (max. 37, min.27).

To evaluate the overall risk of transformation which reduces the potential safeguard of the urban quality and to evaluate its vulnerability, the following subtraction was performed: (matrix of urban quality analysis) - (matrix of transformation risk).

The study of the uncertainty to assess the reliability of the results was supported by the Uncertainty Analysis (UA) based on the Monte Carlo method as in Ligman-Zielinska and Jankowski (2014). The procedure performed is based on the choice of input parameters (weights) assigned according to samples of a Probability Density Functions (PDFs). For each criterion a maximum and a minimum weight were assigned. The variation range be-

tween these limits values turned out to be one or two times the standard deviation of the initial parameters, as described in Moura, Jankowski and Cocco (2014).

In a second step, the Sensitivity Analysis (SA) method (Ligmann-Zielinska and Jankowski, 2014), based on output variance of decomposition, was applied on the criteria weights, to determinate the influence of each criteria on the uncertainty of the S-MCA results. To analyze the variance of decomposition, the variability of the results maps is broken down and apportioned to every input weight, resulting one first order (S) and total effect (ST) sensitivity index per weight.

The S-MCA process, coupled by the UA and the SA, was performed with the variables in vector format (raster to point, Figure 3), with the use of the application "Multi-criteria Evaluation for Discrete Set of Options" developed by Ligmann-Zielinska and Jankowski (2008, 2012, 2014) and Ligmann-Zielinska, Jankowski and Watkins (2012). The final results were re-converted to raster to be represented as a set of maps (Figure 6 and 7).

3.   Results: Process and Evaluation

The characteristics of the Pampulha region, described and highlighted in the work of Faria and Moura (2014) and Teixeira and Moura (2014), are somehow, confirmed by the results of this work. In the previous works, the neighborhoods São Luiz and São José were found to have a lower urban transformation capacity, relatively to verticalization and increase of land use coefficient. They have environmental and cultural characteristics that need to be preserved to maintain their urban quality level, namely preserving the architectural complex, with new projects characterized by low volumetric coefficients, and maintaining green areas and low traffic flow.

Regarding the Process Model (Figure 5) we observe the highest concentration of commercial and residential buildings in São José district where also the largest circulation of vehicles is observed mainly along the avenues Antônio Carlos and Abram Caram. In general the volumetric density of the buildings is not high, nevertheless in São José higher values can be found due to more permissive legislation and consequently affected by building speculation. The concentration of approved projects in the last four years by the municipal government is higher in São José neighborhood, where is evenly distributed throughout the study area. The fragments of vegetation occur in all the area, but they are in greater quantity in the São Luiz neighborhood. The average insolation per building showed high values for the entire study area, demonstrating that the potential distribution of phenomenon is homogeneous among the two neighborhoods.
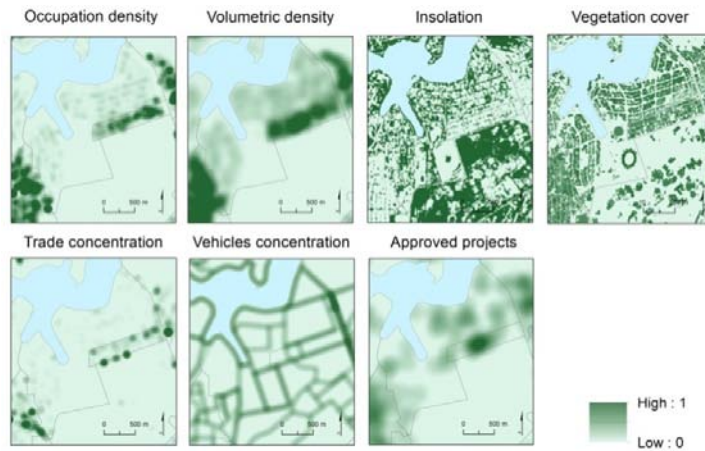
Figure 5. Criteria representing the main processes that describe the study area.

Therefore, two multi-criteria analyses and two uncertainty analysis were developed, considering and not considering the average insolation criterion to evaluate how this criterion is affecting the level of urban quality in the study area (Figure 6).

According to the average urban quality map and considering the criterion insolation (Figure 6-AI), it is observed that the São José neighborhood has a medium-high urban quality level. On the other hand, this same neighborhood features high risk of transformation (Figure 6-A), mainly due to low vegetation cover, high volumetric density and high trade concentration.
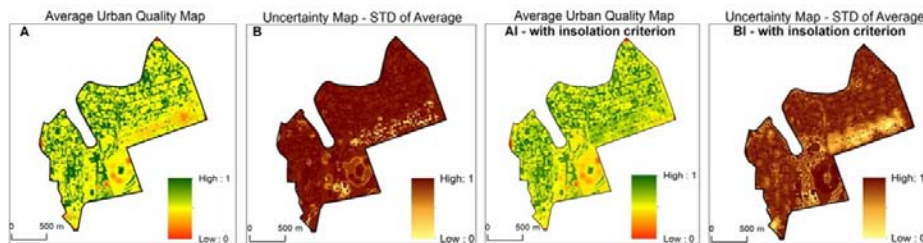

Figure 6. The result of S-MCA and UA to evaluate the processes that characterize urban quality. (AI-BI) with insolation criterion; (A-B) without insolation criterion.

This contradiction is highlighted by the high difference of values in the uncertainty map between the two neighborhoods (Figure 6-BI). In this case the criterion insolation gives São José neighborhood a high urban quality level in an area where the spatial distribution of vegetation, an important criterion for the environmental assessment, is rare.

In general the total-effect (ST) and first-order (S) sensitivity index per weight of the criterion insolation was respectively 0.756, 0.501, and of the criterion vegetation was 0.391, 0.138. These values indicate that the uncer-

tainty (variability) of the urban quality values is basically determined by these two criteria, emphasizing that the insolation criterion has a greater participation in S-MCA results variability. The analysis of urban quality, without insolation criteria (Figure 6-A), can be considered more consistent with the processes that explain how the study area works, that is, higher urban quality in São Luiz and a greater potential for change in San José.

The processes that increase landscape transformation occur with greater intensity in the São José neighborhood, especially by high occupancy rates and great availability of commercial establishments (Figure 7). However, the points of reduction of urban quality within the São Luiz should be investigated because they can represent a catalyst for future transformations. In São José, the risk of landscape transformation represents real threats, reducing the urban quality level, since this area has been receiving an increased number of new projects since 2009.
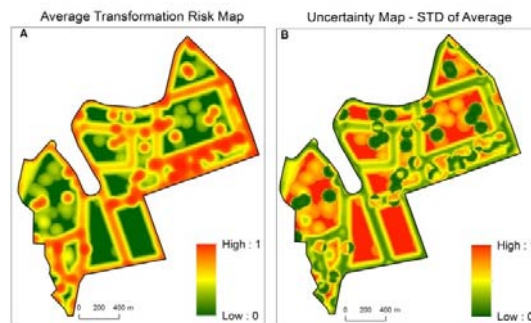

Figure 7. (A) - Transformation Risk; (B) - Uncertainty Analysis.

In Figure 8 it can be noted in red the areas where it is observed a significantly reduced urban quality, both from the initial conditions and the reduction of them for actions of the impact variables.
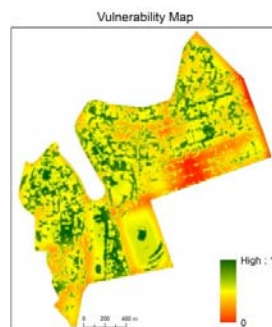

Figure 8. Vulnerability Map: (urban quality map) - (transformation risk map).

The lower quality is more diffused in São José, but the different points within the occupation should be observed, especially in the analysis of which variables interfered in the process, for future studies.

The Uncertainty and Sensitivity Analysis was applied in a complementary manner to the Spatial Multi-Criteria Analysis, aiming at indicating the locations where investigations should be further developed. With regard to the study of urban quality, there is a high uncertainty associated to areas with high potential for maintaining urban quality in the São Luiz neighborhood (Figure 9-B). These areas have great importance for urban quality, but require a thorough investigation regarding the criteria and the weights assigned in the analysis because it is a combination High-High (high interest, high doubt). In São José most areas that have low urban quality level are associated with low uncertainty; the latter areas are of less interest.
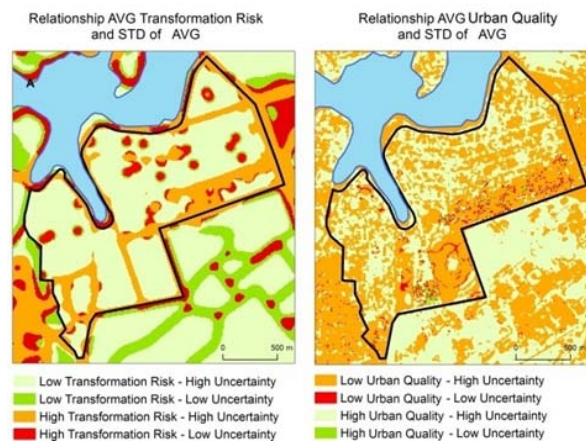

Figure 9. (A) UA of Transformation Risk; (B) UA of Urban Quality.

However, it is also in the São José neighborhood and in the area of the UFMG University Sports Center that the areas with higher urban quality are found in association with low uncertainty. These areas are the most robust in relation to the potential for maintaining urban quality, thus of utmost interest for planning and preservation. These areas occur in a geographically restricted way, in the form of small fragments, in particular linked to the presence of vegetation. In this case it is important to emphasize the fragility of these areas, since they are associated to areas with high risk of transformation.

The USA, complemented the S-MCA, aiming at identifying areas with risk of transformation and demonstrating that sites with high risk associated with low uncertainty correspond to areas where new projects were approved (Figure 9-A). In general, the area shows a low risk of transformation, but the association with high uncertainty means that the variables

may need to be revised, or even that they are important and well chosen, but their concentrations have no geographical correspondence: where is the hot-spot of one is not of the other.

Therefore the synthesis model, which was developed based on the territorial context and on the available data, allowed us to analyze and understand the combined mutual relations between the criteria that we consider important and representative for urban quality.

4. Discussion and Conclusion

This paper presented a part of a larger work which can be considered an early application of Geodesign methods and tools in Brazil through the project approved by CNPq and developed by the GeoLab[1] at UFMG.

The City of Belo Horizonte was one of the first planned cities in Brazil, and for many years was considered as a "garden city". The Pampulha region can be regarded as an area with great potential for maintaining urban quality, but also as an area with capacity of transformation and absorption of new urban projects in a sustainable manner. The region can be, therefore, considered as an area that embodies the concept and the essence of Geodesign, where we can observe a sort of 'implicit geodesign'.

The methodological framework of Geodesign, implemented so far, was very important to understand how the study area works, and which Representation Model may be used to describe the processes, and thus to evaluate whether the study area is working at its full potential and if and how it may be changed. In this context an USA completed the S-MCA and provided a robust support to decision-making with the identification of the areas that explain the functioning and existing interrelationships between the processes analyzed.

Acknowledgements

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[1] http://geoproea.arq.ufmg.br/projetos/mpot

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