Geotechnologies in management of conflicts of interests in urban areas in remarkable landscape of Quadrilátero Ferrífero, Minas Gerais, Brazil

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Abstract
The occupation of the interior of Brazil happened because of mining resources, in a territory called "Quadrilátero Ferrifero", that until today is a mining area, specially in iron exploitation in open pit caves, and gold in underground mines. This economy was responsible for developing the urban network with concentration of occupancy in urban areas surrounded by mining activities, in a complex landscape with conflicts of interests. The interest in landscape protection and planning is still very new, and the study proposes a methodological framework, based on geodesign, to characterize, analyse and to identify values which can translate the essence of the landscape in the area. The framework is based on representation, classification of satellite images, topographic and hydro resources representation, process and evaluation models, that composes a first portrait of the reality to give support to decision making in policies to maintain the essence of the landscape.
Keywords: Territorial Planning; Landscape Planning; Geotechnologies; Multicriterial Analysis; Geodesign.

1. INTRODUCTION

Two centuries after the discovery of Brazil, the interest in occupying the interior of the country started because of the accidental discovery of mining resources, specially gold and diamonds, that supported the long colonial age of building the first cities, recognized today as human cultural heritage. The region called "Minas Gerais" was first visited by explorers guided by the complex of mountains which compose the area recognized as "Quadrilátero Ferrífero" (iron quadrangle), where gold and iron were exploited, and the iron have such an expressive quality that gave the name to the mineral in the World (The iron of "Itabirito"). This economic activity had always been the base of culture setting in the territory of Minas Gerais, and determined the construction of urban network.

The Quadrilátero Ferrífero (QF) presents the most important urban network in central area of Brazil, with 95% of population in urban areas, that grow together with mining activities in the landscape. It presents conflicts of interests related to environmental protection (as it's an area of water resources with headwaters and expressive vegetation cover), economic activities (mining exploitation and the spread of urban territories), cultural and scenic values (it's an amazing setting of beautiful mountains and presents historical cities from the XVIII century).

The recognition of landscape values and the interest to preserve the essence of the place is very recent in Brazil. Only with the law "City Statute", published in 2001, and the "Brazilian Cultural Landscape Stamp", from 2009, the interest in landscape values was declared, but there are not established methodologies to identify, to classify, to characterize and to propose sustainable anthropic use of the territory, considering the protection of the landscape values. Because of that, the goal of the study is to present methodological possibilities based on geotechnologies, more specifically the GIS and spatial analysis models based on Geodesign, to start a process of identifying, planning and managing Brazilian landscapes.

The methodological steps are based on representation of landscape in principal variables, construction of database with georeferenced information, and the application of spatial analysis models. Studies of descriptions of landscape were promoted, composed by the writings of the first naturalists which arrived in the territory, the perception of the inhabitants about it and the identification of nowadays values in each variable. The studies resulted in the production of thematic maps representing the main components of the territory, and the surfaces were integrated by multicriterial analysis. The synthesis identifies the portions of landscape which represent more significantly the elements which translates the essence of the landscape in the QF and the typical portions of landscape with common values. With the results obtained is possible to begin the discussion of adequate use of the remarkable landscape of QF, the management of conflicts of interests, identifying the adequate areas to the anthropic use of the territory.

Geotechnologies have already achieve the status of not been only a data collection, but the goal is to develop models to represent territorial conditions and support policies development. This is the "Geodesign" phase, which proposes a framework to supports decision-making, based on steps represented by models, that are adaptable to reviews, in order to respect stakeholders values. Geodesign was proposed by Steinitz [1] as a framework of models of characterization, analysis, landscape simulation and proposition; with decision iterations striving to allow different actors' comprehension and participation in decision making of their common territory.

Miller [2], defending Geodesign's proposal, used the precept "*The best way to predict the future is to create it*". If the research arrives to the point of presenting a "*Territorial Plan for Landscape Protection and Transformation*", considering the variables which make it remarkable in geographic and cultural sense, the future of the landscape will maintain the essence of the place.

2. MATERIALS AND METHODS

The framework of Geodesign was applied to support decision making in the identification of the "essence of the landscape" in QF. The process proposed by Steinitz is organized in six questions, reviewed at least three times in iterations to adapt the models (Figure1). The flowchart depicting the process shows that the first three questions ("How should the study area be described?" "How does the study area operate?" and "Is the current study area working well?") refer to the problem description or assessment. The next three questions refer to a desired future state or intervention ("How might the study area be altered?", "What differences might the changes cause?" and "How should the study area be changed?").

The author proposes to develop the hole project in three iterations, as the figure shows. The first iteration is constructed from top to bottom, to answer "Why", as it's a process oriented to data, descriptive process, to understand the study area. The second iteration goes from bottom to top, to answer "How" because the goal is to specify more clearly the models as it's a process oriented to decision, to specify methods. The third iteration goes again from top to bottom, throw all the 6 steps, to answer "What", "Where" and "When", as the goal is to perform the project.

The steps presented in this article arrive until the "assessment" stage, answering the questions "How should the landscape be described", "How does the landscape operate" and "Is the landscape working well?". In the future, the goal is to combine this first geographical and territorial approach with other studies, based on cultural measuring and description, to arrive to a final proposal of a "*Territorial Plan for Landscape Protection and Transformation*", to which the analysis will have to present intervention models, based on the questions about "how might be the landscape be altered?", "what differences might the changes cause?" and "should the landscape be changed?". The first steps represented by the three first questions are to characterize the territory, and the steps that follow, represented by the three last questions, have the goal to plan a future desired condition.

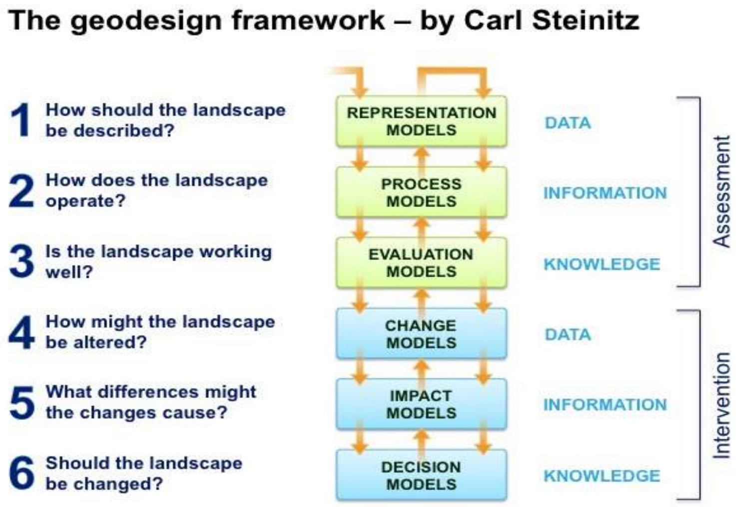
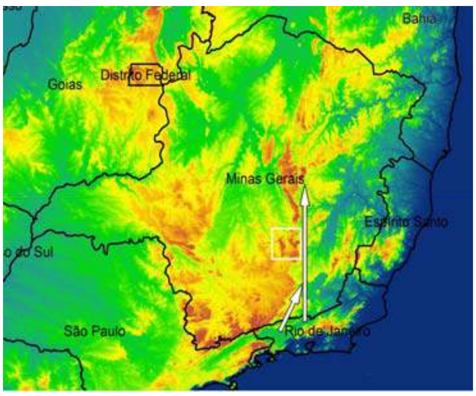


Figure 1. Carl Steinitz framework for Geodesign [1]

2.1 Representation Models

The first step to propose the representation models to the area was to study the construction of the image of the territory in history, to understand their main values and characteristics, mentioned from the beginning until today. The mining area recognized as "Quadrilátero Ferrífero" is a quadrangle area where geology produced amazing landscapes and minerals. To arrive in QF the first travellers followed the axis of a group of mountains that goes from the coast of Rio de Janeiro until the core of Minas Gerais. In the highlands of these mountains they found mining resources and the geological complex that until today represent the image of the state of Minas Gerais. This line of mountains became the reference to the travels along the territory, and to the setting of the first colonial cities, which were cities constructed because of gold exploitation. (Figure 2 and Figure 3). Some naturalists came to Brazil to describe the society, the values, the way of living and the nature (Saint-Hilaire, from 1816-1822; Spix and Martius, from 1817-1820). They wrote about the geography, the mountains, the rivers, the expressive vegetation of Atlantic Forest and a vegetation that is native on iron mineral soils, called "*campo rupestre*" (rock fields). (Figure 4 and Figure 5).

The Representation Models, with the goal to answer "How should the landscape be described", presented the data about geomorphological and environmental aspects, anthropic characteristics and historical heritage aspects, and demographic and socioeconomic aspects.



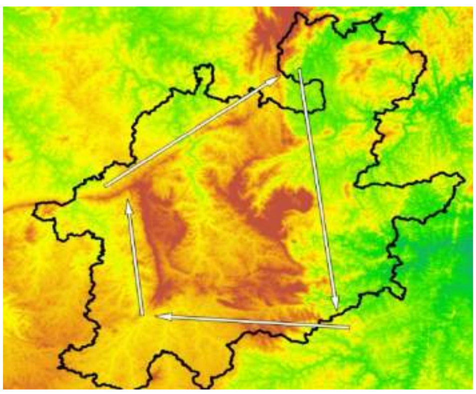


Figure 2. The mountains axe from the coast to Minas Gerais. **Figure 3.** The Iron Quadrangle


Figure 4. Atlantic Forest (Fonte: IBF) **Figure 5.** Campo rupestre (rock fields) (Fonte: ICB/UFMG)

2.1.1. Geomorphological and Environmental Data

a) Construction of Digital Terrain Modeling using AsterDEM data.
b) Construction of Hypsometric Map, extracting the elevation which represents the main topographic conformation, according to descriptions and the essence of landscape.
c) Construction of Slope Map;
d) Classification of Geological Map according to typologies which represent the essence of the landscape, related to iron minerals, quartzites, phyllites, Itabirite ore and their complexes. It was applied a classification proposed by Parizzi et al. [3].
e) Classification of Geological Map according to potential to urban and anthropic occupation. It was applied a classification proposed by Parizzi et al. [3].
f) Mapping of Conservation Units, areas protected by law, according to the levels of protection (sustainable use or integral protection). Data provided by state agency for environmental protection.
g) Digital Image Processing in Landsat image and in Rapid Eye Images. The Landsat image was used to map the forest vegetation, and the Rapid Eye Image was used to identify the rock fields, as they are very difficult to be separated from exposed soil of rock soils. The Landsat is from 2005, resolution of 28.5m, composition 3B4G5R, classified by segmentation and Bhattacharya classification method, and the software used was SPRING/INPE, developed by Brazilian National Institute for Spatial Researches. The Rapid Eye is from 2012, resolution of 5m, composition 3B4G5R, classified by segmentation and Bhattacharya classification method, in SPRING/INPE.
h) Because the classification of images was producing some confusions about the rock fields, the classification made by the IEF/UFLA (State Forest Inst./Federal Univ. Lavras) was adopted.
i) Mapping of areas of exploitation and of prospecting permission to mining activities. The data were collected from National Department of Mineral Research, and only mining areas of gold and iron were selected. There were represented the area of the mine and the cave itself.
j) Mapping of water resources, based on the water network was obtained from IBGE (Brazilian Institute of Geography and Statistics). The original digital data represented the whole hydro channels, and not only the water channels (channels in which the water is always present). A detailed work was developed to separate the levels of channels to represent only creeks, medium and larger rivers.

2.1.2. Anthropic characteristics and Historical Heritage Data

a) Production of polygons of urban areas. The mapping was done with a group of sources. The first step was the Digital Processing of Landsat image, but it was necessary to adjust the polygons because some areas had expressive vegetation cover or rock areas that were mixed with urban occupancy. The polygons adjustment was based on comparisons with high resolution images.
b) Mapping of the road system merging data from streets network, road network and all the road axis. The polylines from the street network presented the information about the hierarchy of the street (avenue, high way, street, square, expressway, alley and so one), and they were classified to represent not only the distribution but also the traffic capacity of each element.
c) Mapping of cultural, natural and historical heritage was a very demanding work. Tables and texts with the descriptions of the areas and of the monuments were read and translated to tables with name, typology, description and coordinates, in order to be transformed to georeferenced maps. The elements were also selected according to their report to mining activities.

2.1.3. Demographic and Socioeconomic Data

a) Urban areas census polygons data and table link construction were based on identifying code of the census collection. The main variables selection is expected to produce a portrait of the demographic and socio-economic aspects in the territory.

2.2 Process Models

The use of the process models is to answer the question "How does the landscape operate". The goal is to understand the spatial distribution of the variables and the logic and the importance of this distribution. Each variable mapped in the first step were treated to be represented in a "Potential Distribution Surface", which is a raster surface determining the importance of the spatial arrangement and producing a quantitative representation to each variable according to its importance to landscape value and protection. The logic is to transform the spatial distribution in a grid, in which each position has a value, according to the goal of the analysis.

2.2.1. Geomorphological and Environmental data

Spatial Distribution Analysis and representation, produced in "Potential Distribution Surface" were:
a) Topographic altitude that represents the QF landscape according to collective imaginary.
b) Geological Groups, highlighting the typologies that correspond to mining areas of gold and iron.
c) Geological Groups, highlighting the typologies that correspond to fragile areas that must be protect because of geotechnical hazards and environmental resources.
d) The hydrology data were treated in order to highlight the concentration of water channels. The spatial distribution model was the Kernel Density, applying weighs according to the level of the channel (simple channel, riverside and river).
e) The areas of exploitation and prospecting permission to mining activities were represented applying weighs according to the potential of transformation: the areas of exploitation where considered of more probability to transformation than the areas with prospecting permission.
f) The vegetation cover highlighted the areas of forest and of rock fields, and the weights were applied according to the importance of preservation.
g) The conservation units according to the level of protection: sustainable use or integral protection.

2.2.2. Anthropic Aspects and Historical Heritage data

Spatial Distribution Analysis and representation, produced in "Potential Distribution Surface" were:
a) The urban areas where represented as areas with potential of transformation.
b) The road network was classified according to traffic capacity of each line, and it was used Kernel density to analyze the concentration of roads and streets and the impact of traffic activities.
c) The points of cultural and historical heritage were analyzed according to Kernel density, applying weights that considered if the place was of official heritage or cultural catalog.

2.2.3. Demographic and Socioeconomic Data

This group of data was represented in census polygons and the construction of the "Potential Distribution Surface" was based on the distribution of a collection of variables: water supply, sewage services, garbage collection, electric energy, number of residences, number of households rented, number of residences in bad conditions, number of inhabitants, rate of inhabitants per residences, average income, level of literacy. To each variable was produced a map considering five levels of conditions: high, medium to high, medium, medium to low and low.

2.3 Evaluation Models

The Evaluation Models have the goal to analyze: "*Is the current study area working well?*" Based on the results of this assessment step, the intervention process could be initiated, with proposals, through the models of Change, Impact and Decision.

To analyse if the area is working well, two synthesis maps where produced: Synthesis of Probabilities of Transformation and Synthesis of Landscape Values. The Synthesis of Probabilities of Transformation presents a combination of factors that can change land use and land cover, such as the growth of the cities, the impact of roads that are understood as elements that catalyse the land occupation, the presence of mining exploitation or the permission to prospect new mining activities. The Synthesis of Landscape Values presents a combination of concentration of water resources, scenic resources based on topographic aspects highlighting the higher altitudes, presence of forest or rock fields vegetation, geological typologies that represents the essence of the QF landscape, conservation units, concentration of cultural and historical heritage elements.

The construction of the synthesis was based in Multicriteria Analysis. According to Moura [4], Multicriteria analysis is a procedure often used in geoprocessing, since it is founded on the basic logic used when creating a GIS: selection of all main variables which characterize a phenomenon, therefore undergoing a methodological reduction of reality and simplifying spatial complexity; representation of reality according to several variables, organized in information layers; analysis plan is represented in cells according to spatial resolutions, adequate both for data source as for objectives to be met; promoting the combination of variable layers, integrated into a system which traduces reality's complexity; and finally, possibility of validating and calibrating the system, upon identification and correction of relations built between mapped variables.

In Multicriteria Analysis, to combine the variables is applied a weighted average map algebra, and the values of the weights chosen to each variable is subject of interests in researches. Moura et al. [5] points that the logic can be to consider specialists opinions, in processes like Delphi or Saaty classification, what is called "knowledge driven evaluation"; or to consider the distribution of data based on samples chosen along the territory that are considered references to the goal of the analysis, that are submitted to data mining, and this logic is called "data driven evaluation". In the study case it was chosen to apply equivalent values to all the variable, as it's still in the first iteration of Geodesign process. In the second iteration the goal will be to review the models, and then the variables can receive values according to a range obtained in a decision process.

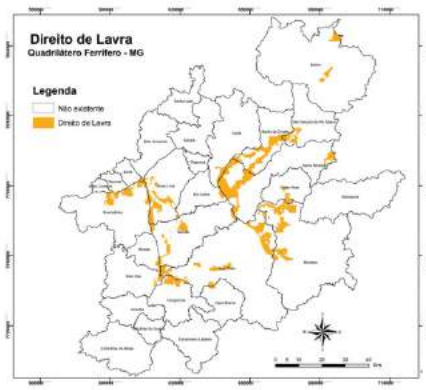
3. RESULTS AND DISCUSSION

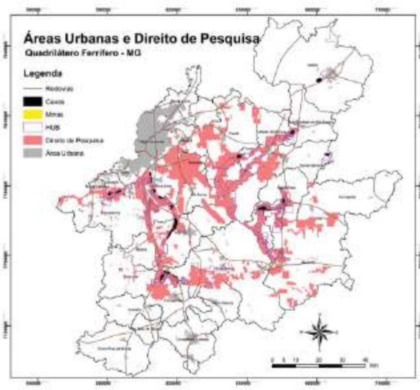
The research arrived the point of Assessment Analysis, which means to present a first characterization of the territory, and as a portrait of geographical aspects, considering physical and human variables. The next steps will provide the portrait of perception aspects, considering cultural values and the points of view according to citizens in a larger time – from the registration in historical documents up to nowadays opinions and expectations. In the Assessment Analysis three steps were followed, based on the Models of Representation, Process and Evaluation; which produced, respectively, Data, Information and Knowledge. (Figure 1).

3.1. Representation Models – Production of Data

A group of maps presenting Geomorphological and Environmental data, Anthropic and Historical Heritage data, and Demographic and Socioeconomic data was produced. The goal was to present the reality through main variables which could explain the territory. While mapping and georeferencing data it was possible to construct the first view of the territory. The cartographic representation, from zenith axis, is not the nature point of view of citizens, and because of that it requires mental construction of topologies and territorial relations, to put the observer in conditions to understand not only the data, but, what is most important, the reasons why the entities and events are in certain places. This first step, based on thematic maps, is more analytical, as it's a decomposition of the reality in variables, but in each single variables it's possible to compose a synthesis understanding its territorial distribution.

The first group presented in Figures 6, 7 and 8 allows to understand the distribution of caves and authorized areas for exploitation (Figure 6), the areas to which there are permissions to prospect possibilities to mining activities (Figure 7), and it was interesting to compare the roads network and the position of the mining activities (Figure 8). The analysis of the maps shows how puzzling are urban areas and mining activities and the importance of this economy to the future of the landscape.





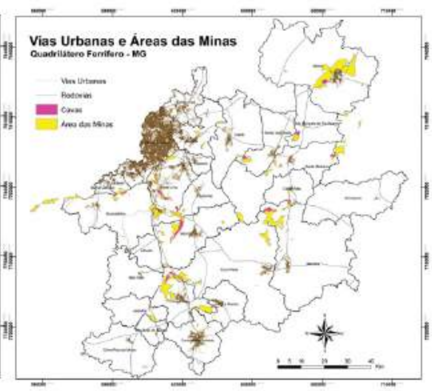


Figure 6. Mining exploitation. **Figure 7.** Prospecting areas. **Figure 8.** Roads, Streets and Caves

The group of maps in Figures 9, 10 and 11 presents the importance of natural resources in the territory. It's a very important area for water resources, characterized by the presence of headwaters and the begging of watersheds (Figure 9). It presents dense vegetation, in forests and rock fields. (Figure 10). The protected areas are not expressive, because in the area of sustainable use the occupation occurs the same way it's done in the rest of the territory. (Figure 11).

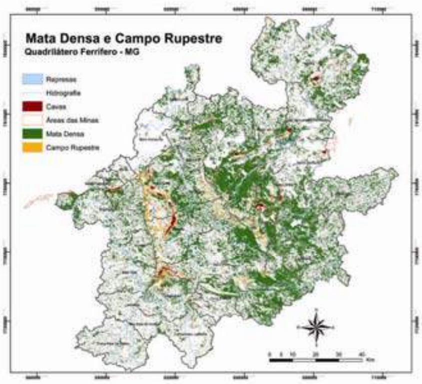
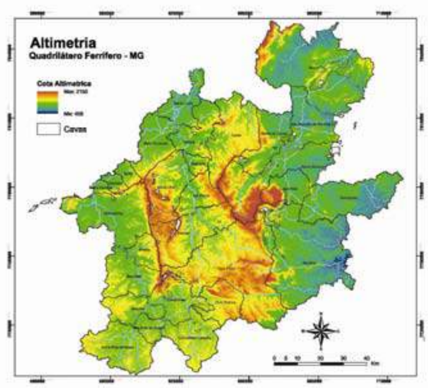
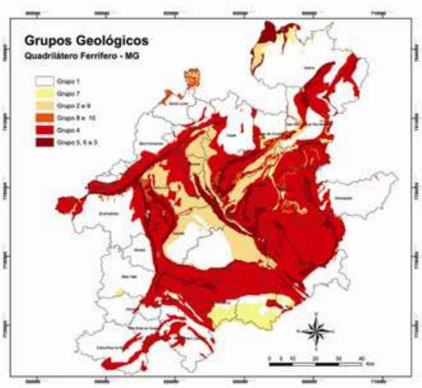


Figure 9. Water resources. **Figure 10.** Forest and Rock Fields. **Figure 11**. Conservation Units.

In the study of geological and geomorphological aspects, more specifically lithology aspects, it's possible to understand why this area is so important, representing to the main economic activity to the state of Minas Gerais. It's an area of a complex and very rich variety of geology, that produced geomorphological results in a unique landscape. The top of the mountains are conformed by resistant structures of iron minerals, mixed with quartzite, and this creates the beautiful geomorphological composition. In Figure 12 the topographic and altimetric landscape is represented. In Figure 13 the lithological types were composed in groups, according to the classification of Parizzi et al. [3] with the objective to highlight the main geological types which are recognized as the imaginary landscape of the QF. In Figure 14 it's presented the analysis done by Parizzi et al. (op. cit) that classifies the groups according to the potential to receive urban occupation, and the conclusion is that the axis that goes south, which are the main areas where urban growth is happening, the territory has low geotechnical stability and potentials.





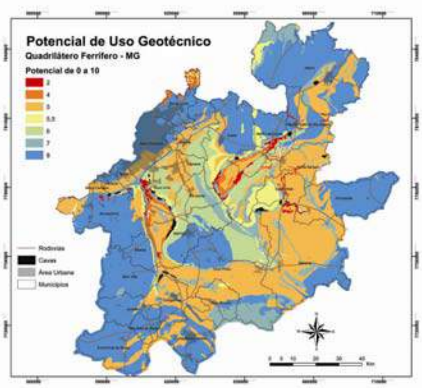
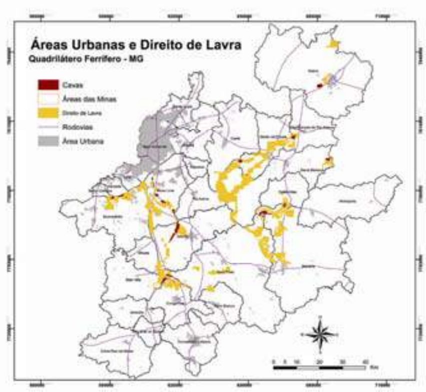


Figure 12. Altimetry. **Figure 13.** Main landscape composition. **Figure 14.** Potential to urban use.

The group of Figures 15, 16 and 17 represents the distribution of urban areas and historical and heritage areas. The goal is to analyse the anthropic use of the landscape, the combination through urban territory and distribution of the mining areas and the cultural resources which were produced in human activities from the beginning of QF occupation. In Figure 15 is observed the conflicts of interests in urban growth and mining areas, with the cities growing to territories that are not considered adequate to occupation in geotechnical aspects. In Figure 16 is represented the axis of “Estrada Real”, the old road used in the past by the travels and the transportation of gold and diamonds, with cultural and natural attractions. Figure 17 represents the distribution of historical heritage monuments and areas ,constructed because of mining activities.



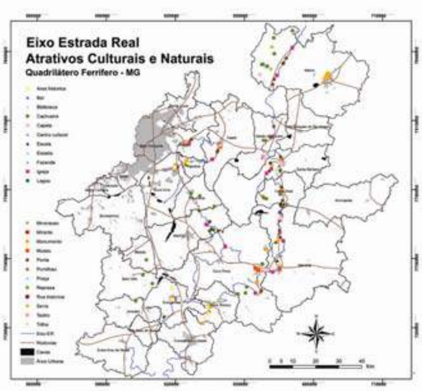
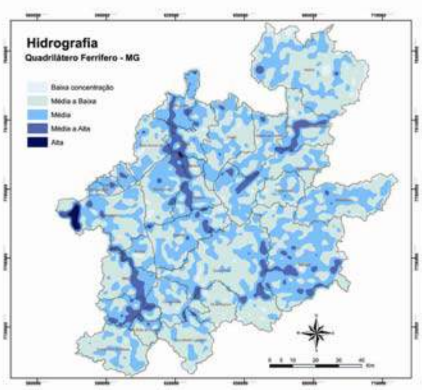


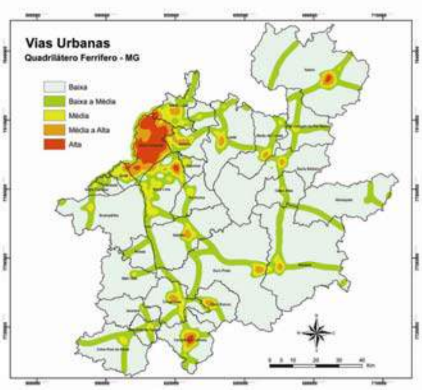
Figure 15. Urban areas & mining. **Figure 16.** Axis of Estrada Real. **Figure 17.** Historical Heritage.

3.2. Process Models – Production of Information

The data produced was treated to compose layers of *Potential Distribution Surface* in order to transform data into information. The goal was to allow the interpretation of variation distribution in space, highlighting areas of concentration or of lack of the activity, service or resource. The Figures 18, 19 and 20 are examples of this spatial distribution in a grid of values that make possible to identify areas with most expressive water resources (Figure 18), with concentration of roads network (Figure 19) and of concentration of cultural and historical heritage areas (Figure 20).

Observing the presence of areas almost without roads and occupation, it's possible to say that, until today, the natural resources and the remarkable landscape were not in conflict of urban occupation: some spatial landscape where preserved and the urban network had a natural geodesign. This concept, “natural geodesign”, what defended by Steinitz [1] when he explains that if anthropic use of the territory respects natural constraints, this composes a natural geodesign. In QF it happened in the scale of regional analysis, but if the observation goes to the scale of local analysis probably some conflicts will be observed. What must be considered is the interest to urban growth to the axis of natural and landscape resources, because the consequence will be the disequilibrium of this natural geodesign occupation of QF.





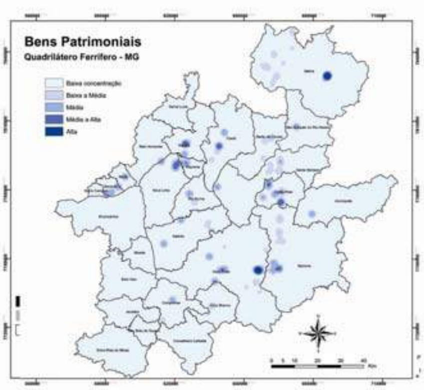
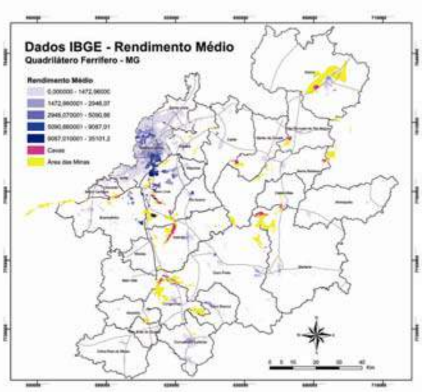
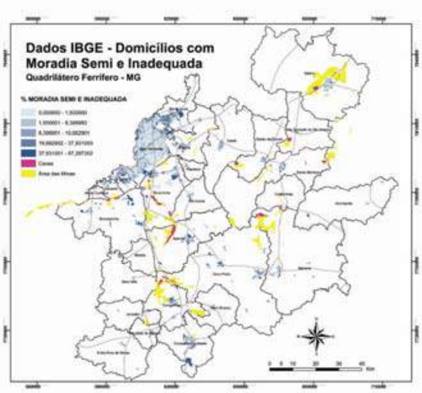


Figure 18. Water concentration **Figure 19.** Roads concentration **Figure 20.** Heritage concentration

The transformation of data into information was also done with demographic, social, and infrastructure variables. The goal was to analyze if the areas that receive economic activities, that are mainly mining activities, show the economic results in a better life condition, measured by the presence of infrastructure and the conditions of the residences. A total of 11 variables were analyzed, and Figures 21, 22 and 23 area examples of this distributions analysis.

It can be observed that the higher income is concentrated in the capital of the state (Belo Horizonte), and is not spread in the hole territory. In the capital, the concentration of higher rate of income is in the south, confirming the risk of urban growth and interests to this axis, breaking the geodesign equilibrium in the remarkable landscape (Figure 21). Considering regional scale, the concentration of residences in not good conditions is not observed in areas close to mining activities. If the scale changes, it can be seen that this cities in the territory are very poor considering the amount of money produced by mining royalties and services (Figure 22). The territorial distribution of density, number of inhabitants per area, is a mirror of Brazilian's way of distribution in the territory, which is: concentration and verticalization in larger cities, and not a spread occupation in the territory. This, considering the point of view of landscape protection interest, is good, but results in lack of quality in huge cities. It's also interesting to observe that the axis east is quite unoccupied, considering cities and roads network.(Figure 23).





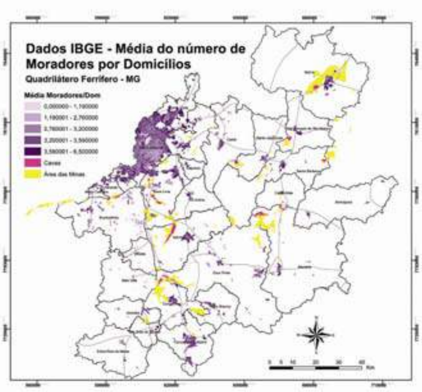
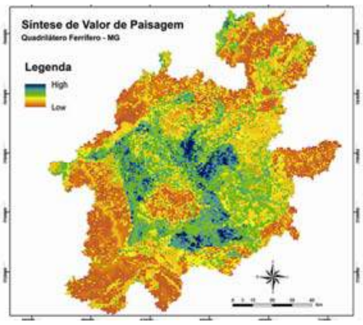


Figure 21. Average income. **Figure 22.** Improper conditions residences. **Figure 23.** Density Rate

3.3. Evaluation Models – Production of Knowledge

It was produced a first group of evaluation models, to combine the variables according to interest and preservation and to possibilities of transformation. In the group of interest for preservation there were combined variables that explain the main characteristics of the remarkable landscape of QF (Figure 24). In the group of possibilities of transformation it was combined a group of variables that represents the presence of anthropic uses related to mining activities or urban activities (Figure25). The goal was to identify the complex of values which represents the essence of the landscape, but also the use of the territory highlighting the concentration of activities that must be well developed in order to maintain the natural *geodesign*.



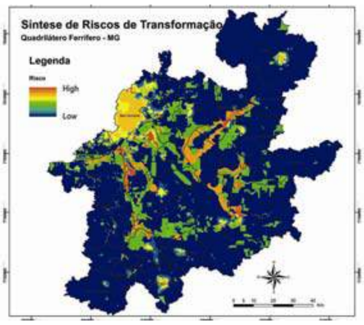


Figure 24. Remarkable Landscape. **Figure 25**. Areas with tendency toward transformation

4. CONCLUSIONS

The article presents a case study based on geodesign analysis that arrives to the step of Assessment about the territory. The results were based on geographical aspects, considering the variables that are integrated in a systemic arrange which, because of this specific combination, produced the remarkable landscape of Quadrilátero Ferrífero. It's remarkable due to the beauty of the landscape, but also because of economic resources of mining activities, and because of historical architecture and urban compositions in which the culture from the state began. But it's also an area of conflicts of interests, due to urban growth is the axis of remarkable landscape and of mining activities.

The research will be continued from the step of Assessment to the step of Intervention, to give support to decision making in policies to the territory. In the next steps it'll consider stakeholder opinions and go deeper in cultural aspects. To complete the geodesign framework, more iterations in the models must be provided, to review this first portrait of the reality. The final result will contribute to the proposal of a "*Territorial Plan for Landscape Protection and Transformation"* which will be important not only to "Quadrilátero Ferrífero", but to promote discussions on methodologies to identify, characterize and presents proposals to landscape management in Brazil.

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