Aerial Images and Three-Dimensional Models Generated by RPA to Support Geovisualization in Geodesign Workshops

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Abstract. Remotely Piloted Aircraft (RPA) are geotechnological instruments with good cost-benefit, as they provide quick spatial data capture with satisfactory accuracy and resolution, affording the creation of three-dimensional products and aerial photographs from different perspectives. These data have been used to support geovisualization in geodesign workshops held in socially fragile and poor communities, in which people of the place have a vast knowledge about their territory but difficulties in working with cartographic representation and maps products. This study, therefore, presents the experiences earned in three geodesign workshops held in Belo Horizonte, Brazil, when aerial images in an oblique perspective and three-dimensional models with interactive navigation were used. The results allow us to conclude that the use of fields of view with an oblique perspective to the objects of analysis promotes a link between the zenithal cartographic expression and the immersive view in the landscape, which is a way for the formation of the mental maps. That is understood as an essential condition for the promotion of citizen participation in co-design processes, based on geovisualization and the sense of digital inclusion.

Keywords: Geovisualization · Geodesign · Remotely Piloted Aircraft

1 Introduction

According to the latest demographic census conducted in Brazil, 6% of the country's population resides in subnormal agglomerations, which are the places popularly known as "favelas" (slums) that are socially fragile and poor communities. These are defined based on the precarious condition of the household's infrastructure, and the data show that in the subnormal agglomerates only 67.3% had sewage collection, 72.5% installed electricity, and 88.3% piped water supply. Most of these households (49.8%) are in the metropolitan regions of the Brazilian southeastern, and frequently these areas are inappropriate to housing, such as steep slopes, caves, riversides, among others [1].

O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12252, pp. 296–309, 2020.
https://doi.org/10.1007/978-3-030-58811-3_21

In the Metropolitan Region of Belo Horizonte (MRBH), which has 5.4 million inhabitants, 9.1% of the population lives in subnormal agglomerations, that is, approximately 491 thousand people. In other Brazilian regions the condition is even more severe, for example, Belém, which has 53.9% (1.1 million people) of the population living in slums; Salvador with 26.1% (932,000 people); São Paulo 11% (2.16 million people); and Rio de Janeiro 14.4% (1.7 million people) [1].

Considering only the city of Belo Horizonte (BH), the total population is 2.4 million inhabitants, and according to the Brazilian census data, 307 thousand people are in subnormal agglomerates, that is, 12.96% of the people. However, the municipality officially considers 209 villages and slums in the city, which means 714 thousand people (27.4%) living with poor access to basic sanitation and urban infrastructure [2].

In order to promote faster improvement at these locations, the municipality is using the geodesign methodology to hold hearings with the population as a basis of citizen's participation in planning and decisions [3]. However, the experience in conducting geodesign workshops in these places has shown us that the use only of thematic maps and evaluation maps as a way to represents the information and characteristics of the study areas have not been successful in communicating spatial information. Although people of the place present a vast knowledge about the territory where they live, they commonly have issues in understanding maps because the zenith cartographic view is unusual for them, there are many generalizations and conventions which require a capacity of abstraction and the spatial analysis models used to generate the evaluation maps are too complicated for this audience.

These empirical perceptions led us to propose other methods of visualizing the territory in order to improve the condition of geovisualization and, from that, provide a shared basis for the discussion of the proposals resulting from the geodesign workshop. Another issue inherent to this situation is the lack of spatial data to work in these areas that present intense dynamics of territorial transformation since each day new families are installed in and, in most cases, without planning and basic needs of infrastructure.

It is worth mentioning that the local population is undoubtedly the group most directly interested in the projects and discussions and that the promotion of geovisualization, in this case, has a crucial role in including them with similar conditions of debate for the proposals and policies presented in order to compose a final design. However, what we notice, in practice, is that the use of only standard cartographic language has promoted an alienation and even omission of people who do not fully understand this language. Therefore, leaving the speech power and the design drawings for those who demonstrate broader knowledge in maps or GIS resources.

2 Use of RPA for Data Collection and 3D Modeling

Based on the issues raised, the proposal is to use Remote Piloted Aircraft (RPA) for the collection of spatial data in order to develop an updated database for conducting the geodesign workshop, as well as to perform 3D modeling and photo captures with oblique angles for geovisualization purposes.

The RPAs have as advantages the high spatial and temporal resolution of the images, the possibility of capturing data flying close to the obstacles, and with different positions of the camera for taking images and the reduction of the operation cost. The work can be carried out in a very agile way, which allows a quick action in critical situations or for constant updating, as in multitemporal monitoring [4]. Besides that, multi-rotor aircraft can take off and land vertically, without a runway, facilitating the process in places with a high density of buildings and steep relief, which are usual features in slums in southeastern Brazil.

Another advantage of the RPA aerial survey is the possibility of defining different levels of image overlap, as well as different camera positions and angles. It allows the generation of georeferenced products even with irregular overlapping of the images, that is, collecting images in complex situations that may not be covered by traditional aero photogrammetry procedures. Besides, it is possible to collect information from the sides of objects, such as building facades or on steep slopes, which allows the generation of realistic three-dimensional models that are quite similar to the object's real morphology.

By using high-precision GNSS receivers combined with data capture with RPA, it is possible to achieve positional accuracy altimetric and planimetric matches with LiDAR data, which opens up possibilities for integration and updating the database in an agile and less costly condition [5].

In this study, we highlight that the use of image captures for 3D representation of the landscape and its elements, as well as the cadastre making, has significantly expanded the conditions for building models that expand the users' view of their territorial realities. It is, therefore, an interest in exploring these geotechnological resources as a support for geovisualization, favoring the establishment of a common language to support the discussions between the parties involved in geodesign workshops.

3 Geovisualization

Geovisualization derives from cartography, and, in this sense, maps must be understood as a visualization tool and not as a simple accessory for communication. Therefore, the map must be understood as an expression of geographical and, thereby, contributing to the identification of patterns that guide new understandings [6]. The tools for visualizing spatial information have to allow us to ask questions about what we do not yet know, and the quality of the visualization is considered a critical component for the promotion of knowledge.

According to MacEachren (2005, 445), *first, visual representations can act as the object of collaboration, thus as an entity to discuss, create, or manipulate. Second, visualization can provide support for dialogue (about information, plans, methods, strategies, or decisions). Third, visual representation can provide support for coordinated activity (thus for compiling information, carrying out plans, or executing decisions)* [7].

We understand that geovisualization should serve to build a link between reality and the mental maps that a user has about reality and, in the context of participatory planning, it should act as a bridge for users to be, increasingly and better, involved in the planning and management of the territory.

It is necessary to create shareable mental models for everyone involved in the process, otherwise, processes that involve many subjects cannot obtain a joint basis for achieving an objective [8]. This concept has been treated as people interoperability, which is linked to the use of geovisualization resources that favor communication between different actors involved in collaborative planning and decision-making processes [9]. It allows the search for protocols that can establish a common language, which is the basis for sharing decisions, for co-creation, and culminate in an effective co-design.

The use of RPA, in this sense, aims to build representative models of reality that provide the actors involved in the process the ability to explore, recognize, analyze, propose, synthesize and present their opinions about the analyzed territory. It is a fundamental condition for citizen participation on an equal basis in co-design processes and, therefore, it is understood here as a valuable resource of geovisualization that can support these processes.

When geovisualization is effectively used, it offers the possibility of engagement, considering that a wide range of users will be able to participate in activities that require or reside on the spatial component [10]. We highlight the ability to change the 3D point of view in real-time as essential to create a sense of virtual reality. It opened up new approaches to visualization that is related to a new degree of cartographic freedom for visual representation [11].

We must keep in mind that the transformation from the real 3D world to the 2D map implies a loss of details and that the elements that make up the territory are represented by generic symbols that do not necessarily have scales relative to the real world, such as point features for example, [12]. In this sense, how data is presented can condition (or even compromise) its interpretation and, in turn, maps have disadvantages to digital models, as it is the reduced interaction between readers and data [13].

Currently, technologies for capturing, modeling, and presenting data assisted by RPA have changed the paradigm of visual representations of territorial information and allow to reduce some communication noises since they reduce subjectivity in the construction of the image through the presentation of realistic models. They use dynamic and interactive platforms that allow navigation in different perspectives, ranging from the zenith that allows a synthetic view to the azimuth that represents human immersion in the landscape, passing through the oblique perspective that allows connections between the navigation axes (Fig. 1).

Currently, we have the opportunity to recreate high-definition three-dimensional virtual spaces that allows us free interaction for choosing the fields of view, such as the human perspective – immersed in the landscape –, the bird's view – which flies overhead but with the freedom to move and to get closer to objects – and from the infinite – with the possibility of understanding the spatial arrangement of the elements. The bird's view, which concerns the oblique perspective, has the potential to combine the centrality of the observer (man immersed in the landscape) with the univocity of the maps (zenithal, synthetic view) [8].

Therefore, these new tools for communicating spatial information, when used creatively, can improve the quality and efficiency of public discussions and debates and

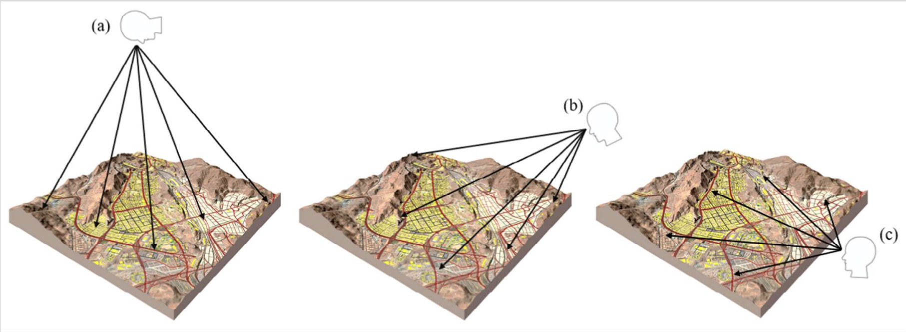

Fig. 1. Viewing Perspectives. (a) Zenithal Perspective: technical view, remote sensing; (b) Oblique Perspective: technical view & human view, technical data capture & human comprehension; (c) Azimuthal Perspective: human view, immersive, in sensing. Source: the authors.

help build community consensus around specific planning issues [14]. It should also be considered that the use of photography for situations in which communication between users is vital for decision-making. It is more significant than the use of cartography because the map is a synthetic decomposition, while photography is closer to user reality [15].

4 Study Areas

This study presents experiences of geodesign workshops with a focus on three distinct communities that present social fragility, located in BH, Brazil, which are the communities: Dandara, Conjunto Paulo VI, and Confisco (Fig. 2). These areas have in common the fact that they are considered as illegal settlements with different morphology and history in comparison to slums: these areas are invaded as they do not own the land, and they do not have official infrastructure installed (sanitation, transportation, water, energy and so one), but they had a kind of a social organization before the invasion (conducted by a group). The result is a more regular distribution of streets and lots, even without following urban planning rules of dimensions, slopes, geometry. Also, two of the areas were identified as of high vulnerability in the face of estimated climate change until the year 2030 [16].

4.1 Dandara Case Study

The illegal settlement of Dandara community is located in the northwest of Belo Horizonte and is one of the largest and in the city. The area was initially occupied in April 2009 by 150 families, but currently, more than 1,200 families are residing there (4,000 people). The support of social movements and other professional and academic groups provided that occupation took place in a very orderly manner, with an urban plan drawn up collectively for invasion, which considers the topographic and

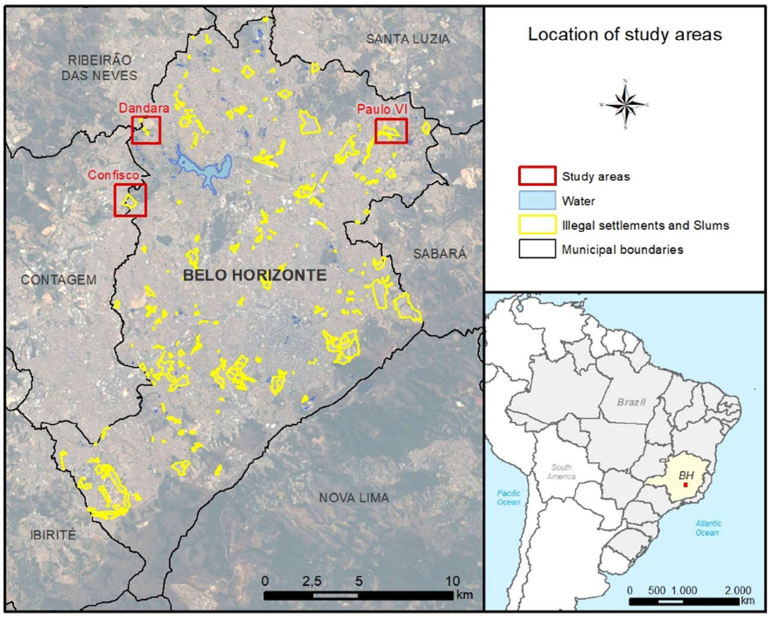

Fig. 2. Location of study areas. Source: the authors

environmental characteristics of the area for proposing the subdivision in streets and lots [3]. However, the place is still undergoing a process of urban regularization and, consequently, the installation of necessary sanitary infrastructure.

From 2016 the area begins to receive investments for urban regularization and provision necessary sanitation infrastructure and other public services, and the geodesign methodology was chosen in order to optimize the discussion process with the local population since the methodology applied previously could take up to two years to complete the study.

Then, data surveys and three-dimensional modeling were carried out with the support of a multi-rotor RPA to update the existing database as well as to test the use of a three-dimensional model of the area as a geovisualization resource. Considering that it was an extremely needy community and that some people were not wholly literate, the use of this model was proposed as a means so that all participants could have the same conditions to understand the information worked on.

Before the workshop, training was conducted with young people from the community to use digital platforms, using the computer laboratory of a public school in the area and, during the workshop, they could act as resources for their parents or other adults and elderly in the community.

It was evident that since the first contact with the 3D model and the digital data displayed on a web map, the local population tended to use them, at the expense of the maps printed on paper and the systems made available on the *geodesignhub* platform. The participants received printed materials, a web-based platform with information, and the 3D models, and we were able to observe and compare their performance. The dynamic data visualization, as well as the possibility of alternating perspectives, were identified as the main gains in geovisualization that contributed to the local population to recognize the territory features.

As the geodesign team has to propose diagrams on a two-dimensional geodesign platform, an effort was made to link map and 3D model orientation using the north as a reference. In this way, the participants started to use, to understand, and even to trust in the information presented in the evaluation maps, since there was the support of the realistic representation of the territory.

This experience showed us that the dynamic and intuitive tools of geovisualization favor the construction of mental models, self-learning, and the construction of knowledge. While using only thematic maps of defined systems, skip stages of the cognitive process related to the abstraction of spatial information, and does not provide the basis for understanding information effectively. Thus, geovisualization contributes to citizen participation in debates for co-design, as they favor the establishment of a common language as all actors can interpret spatial information at a similar level os comprehension [9, 14] (Fig. 3).

Fig. 3. Geodesign workshop in Dandara community, BH, Brazil. Source: Monteiro et al. (2018) [3].

4.2 Conjunto Paulo VI Case Study

Based on the experience in the Dandara community, a method was sought to measure whether the use of three-dimensional models elaborated with RPA, in fact, provides gains in geovisualization. For this, during the geodesign activities scheduled for the Conjunto Paulo VI illegal settlement, children were invited to participate in the activities with the proposal to raise their awareness of the existing problems in the neighborhood and to include them in listening processes about the current demands and proposals. For us, it was an opportunity to work with a layperson in cartography and observe how the process of understanding spatial information takes place. In this location, there is the presence of irregular settlements under a huge line of electric power transmission from Companhia Energética de Minas Gerais (CEMIG), an area at risk of landslides, as well as other environmental and lack of infrastructure problems.

Data collection with RPA in the area and three-dimensional modeling for viewing on computers were performed. The children participating in the workshop were divided into three groups, been Group A working with printed maps only, Group B working with printed maps and 3D model, and Group C working with 3D model only. In short, children should use the resources provided to answer questions that demanded spatial reasoning by drawing on a blank map (Fig. 4).

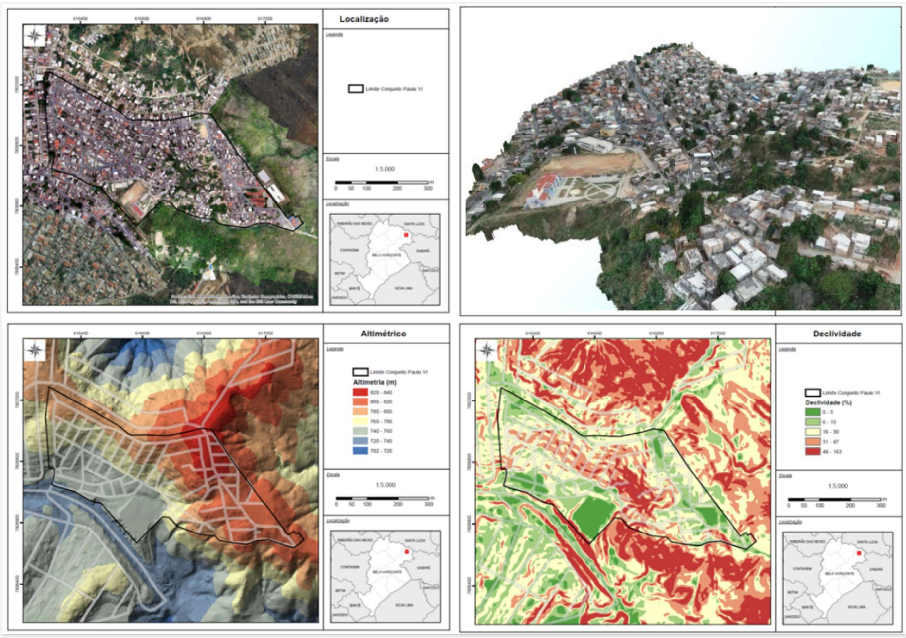

Fig. 4. Maps and 3D model used during the workshop with children. Source: the authors

The first question asked sought to identify the basic levels of spatial reasoning. Children were asked to draw an "X" on the answer sheet to indicate where their home is, an "O" to indicate the location of the Sobral Pinto Municipal School (SPMS) – the place where the workshop was held –, and a line to indicate the location and direction of the existing power transmission line in the neighborhood. This question worked only at the *description level* of spatial information, that is, without involving analysis or inference skills, but only of recognition and understanding of location [17]. *Representational correspondence* is also assessed, which refers to the ability to recognize on the map what is seen in the real world [18].

The second question worked on slightly more advanced levels of abstraction of spatial concepts. Children were asked that, understanding that a watercourse will flow from the highest parts of the land towards the lowest parts, draw a double line to indicate the position and the probable path of the stream that exists in the neighborhood. This question makes it possible to assess the ability to reason Source-Path-Goal demands [17], which involves the perception of movement, the starting point, the way forward, and the destination. This understanding is linked to *directional correspondence*, which relates to the ability to interpret directions and, thus, link the map azimuth with that of the real world [18]. Besides, for displacement reasoning, children needed to analyze the data they had access to and interpret the hypsometric map or the 3D model.

The third and last question worked on the most advanced levels of spatial abstraction. Children were asked to identify on the blank map using hatches where the places at risk of landslides involving victims were. The children were informed that the places at risk are those with houses installed on steep slopes, that is, with high declivity associated with the presence of buildings. The intention was to evaluate their ability to integrate information from different maps comparing to the use of the 3D model that presents the same content, but with another type of visualization. This question required children to analyze different data and reason about consequences from the interaction of information [17]. The solution to this kind of problem is the establishment of *configurational correspondence*, which is the understanding that the relationships between the features present on the map correspond to the relationships between the corresponding features in the real world [18].

As a result of this process, it can be mentioned that the children in Group A (working with printed maps only), in general, knew the answers to the questions, as they deeply knew the territory in which they live. However, the printed maps did not help them to materialize the answers on the answer sheet. In comparison with the other groups, it is clear that this concerns the rigidity imposed by the scale and fixed orientation of the printed map, making it impossible to choose other viewing perspectives or even to change the scale, to enlarge the elements on the map. It requires a higher capacity for spatial abstraction, for recognizing patterns and shapes of objects in an image with a zenith perspective that demands the ability to make associations between map and reality mentally. In summary, the most straightforward questions were answered consistently, but questions 2 and 3, which required a more sophisticated level of abstraction, presented more critical errors.

Children in Group B (working with printed maps and 3D model), were the ones who had the best performance in the activity. It was evident that children were more motivated to search for answers using the 3D model, which indicates that the investigative process and the formation of mental maps could be more consistent. Children who were dealing only with printed maps, although they were motivated to participate in the activity, more quickly exhausted the search options on the map, dispersing from the investigation.

In general, it was noticed in this group that the 3D model provided work in the visual field, that is, easier recognition of information due to its proximity to reality. Moreover, from this recognition, children began to use maps in the search to answer questions correctly, establishing correlations between the 3D model and the map, sometimes counting the number of blocks on the map and in the model, or recognizing some form or specific color identified in the model and on the map with the orthography. All showed comprehension of the terrain shape and obeyed the logic that the watercourse flows from the top to the bottom of the slope, and the drawings, although showing rivers in places where there are no watercourses, followed this premise (Fig. 5). Is was a significant gain because Group A showed inconsistencies in the drawing of watercourses. The children of Group B were also able to correctly identify the places with the most considerable risk of sliding in inhabited places and, also, they had a better sense of the dimension (scale) of the drawings, creating hatches with high precision in terms of area and position. Comparing with other groups, we understand that the quality of the answers of this group is not only in the use of the 3D model but also in its association with the printed maps. The printed maps contributed to consolidate the notion of scale, completing the flow of the abstraction process from the real world, passing through the virtual model, being synthesized by the 2D map and, thus, reaching the ability to express their thinking and understanding in a spatially coherent way and assertive.

The children in Group C (working only with 3D model) presented exciting results concerning the requested three-dimensional analysis, whereas they presented some difficulties for simple localization operations. It was possible to notice during the activity that the children were able to find the answers in the 3D model easily but had

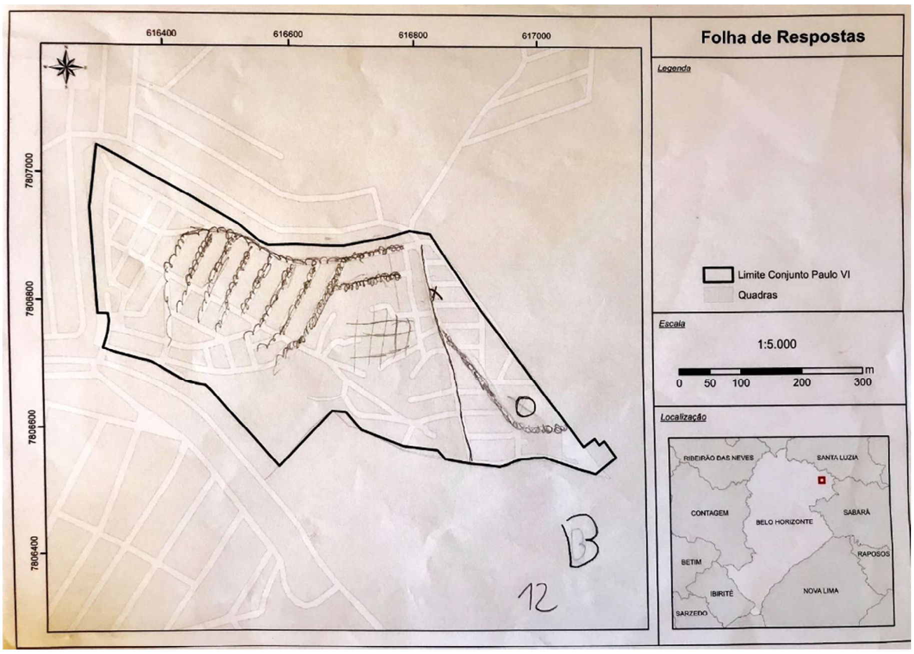

Fig. 5. Sample answer from a Grou B child. The circle represents the School, the "X" represents its home, the hatch represents the risk area, and the spiral lines represent the water flow. All the answers are right or at least coherent with reality.

great difficulty in transposing what they visualized into the model to the blank answer sheet. In this sense, it is understood that the direct transfer from the 3D model to a clean 2D environment is also an incomplete process, with no improvement in the ability to reason spatially through the use of the 3D model alone.

It was evident that only the 3D model, as well as using only the map, does not favor a better understanding of spatial information. However, the concomitant use of complementary information, which is seen in both the 3D model and the printed map, stands out as the best option. In this way, it is possible to recognize the elements in the 3D model initially and then, in a second moment, the use of support maps to enable the conversion of 3D information into 2D.

After this first activity, all children were invited to work with all available resources (maps and 3D model), and, from this moment, the evaluation maps were presented according to the systems established for the workshop. Children were asked to try to associate the information presented on the maps with the other available resources. And then, a geodesign workshop was started with them in order to produce ideas for an alternative future in the neighborhood where they live. It was noticed that they presented a clear understanding of the basic information treated, and, from that, they were able to propose diagrams with an appropriate location, orientation, and scales, showing that the geovisualization process was effective.

4.3 Confisco Case Study

In order to validate previous experiences, a geodesign workshop was held with undergraduate and graduate students in the Federal University of Minas Gerais (UFMG) with the participation of people from the public administration (municipal and state levels, from Belo Horizonte and Contagem city halls, from the State of Environmental Secretary) in order to discuss alternative futures for the Confisco illegal settlement and its immediate surroundings. The study area is considered a fragility zone concerning the possible climatic changes that may occur in the municipality and also the metropolitan region. Besides, it is located on the border between BH with Contagem, a peripheral area where there is a lack of urban infrastructure, and in conditions flood risks, as it is also an irregular settlement area. The initial goal was to analyze in a case study with students from the university if the results obtained in the previous case studies could be similar, testing the methodology of using data collected with RPA to promotes a better geovisualization in geodesign workshops (Fig. 6). The difference and the task in this academic experiment are to work with people that do not know the area but know how to use digital tools. In contrast, in the workshops in the illegal settlements, we worked with people that know the area but do not have the skill and knowledge to use digital tools or cartographic representation. However, soon, the analysis of the results will help to select and represent data in a better condition to the geodesign workshop that will be held with people of the place.

As it is a borderline area between two municipalities, there is an initial difficulty in integrating the existing database, since the municipal governments do not work with an integrated database, but they are raised separately. The mapped area totals 340 ha and surface and terrain, orthomosaic, aerial photographs, and 3D models were generated to represent the area.

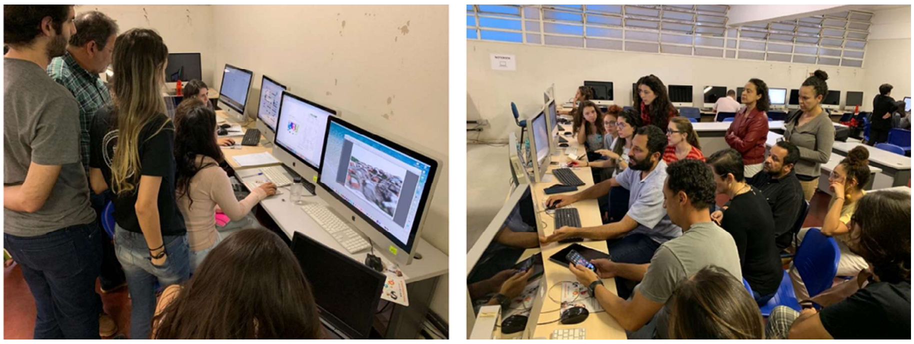

Fig. 6. Participants in the workshop, composed of students from the University and representatives of local governments. Source: the authors

The workshop participants did not know the study area, and during the activity, it became evident that the materials complementary to the maps, such as the 3D model (Fig. 7) and aerial photographs, were essential for understanding the characteristics of the place. It was noticed that the use of these resources to promote geovisualization contributes not only to enable the layperson in cartography to be included in the discussion process. Nevertheless, it also enables experts to recognize the territory more effectively, giving greater clarity to the content expressed in the form of an evaluation map.

Fig. 7. 3D model from Confisco neighborhood and surroundings. Source: the authors

In this sense, the impressions already obtained in the other mentioned workshops were corroborated, validating the proposal to use dynamic visualization platforms that allow scale and perspective free adjustments to support geovisualization, and the formation of shared codes for promoting a shared design.

5 Conclusions

Following the participatory planning processes in Brazil has shown us the relevance of geovisualization resources to support geodesign workshops, especially when working in more needy communities or involving people with little knowledge in cartography. These processes demand not only the understanding of information displayed on maps but also using the spatial information creatively to propose new ideas, that is, the ability to reason spatially is essential for active citizen participation.

All actors involved in the co-creation process must have equivalent conditions of participation and then is recommended to use technological resources for the promotion of geovisualization, which can favor more effective communication between the parties.

It is noticed that in the 3D model, there is immersive navigation that favors recognition and awareness. However, the maps, with synthesis and analytical language, remain essential for thematization of information and planning. In this sense, the oblique view provided by the 3D model bridges the gap between immersion (of the body) and distancing (zenith) and is, therefore, a link of communication between these two perspectives of analysis.

The experiences presented were also successful in terms of capturing spatial data, since it enabled the creation of an updated database through a quick survey, of satisfactory accuracy and low cost. It reinforces that the use of RPA can also favor the autonomy of public agents and researchers to carry out studies.

Acknowledgments. The authors thank CNPq support through the project Process 401066/2016-9, FAPEMIG PPM-00368-18, FAPESC/PRO2019071000025, and CAPES 88887.474274/2020-00 for the support for taking part in the conference.

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