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3D SPACE SYNTAX ANALYSIS

Case study: Casa da Música

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ABSTRACT

The paper will focus on research regarding DepthSpace3D: a 3D Space Syntax analysis software. This new digital tool increases the range of possibilities regarding 3D analysis, which seems to have advantages over current 2D analysis. The case study used to test those concepts was the iconic (and controversial) Casa da Música (by Rem Koolhaas, OMA) and its neighbourhood, one of the centralities of the City of Oporto. It will be argue that 3D can introduce something new to the Space Syntax analysis. The paper has three main goals: i) To analyse Casa da Música and its neighbourhood in its linguistic characteristics (syntax/connotational semantics) and in its functional relations (denotational semantics/pragmatics) to physical/social environment; ii) To compare 2D and 3D analysis (2D software is used to gather a set of data that is paralleled to

3D data); iii) To verify the obtained results within empirical data on human spatial behaviour, assembled from previous research conducted on the same site through automated video mapping. With this new approach, the paper will also reveals a new process to unveil how people use and appropriate its surroundings. Besides this framework, the outputs profits from some additional features of DepthSpace3D: transparency, multiple paths of visibility, attribution of properties to the Viewed Space.

KEYWORDS

3D SPACE SYNTAX, FORMAL METHODS IN ARCHITECTURE, NEW METHODS OF SPATIAL ANALYSIS, MAPPING, REM KOOLHAAS

1. INTRODUCTION

This paper intends to evidence simultaneously two different sets of assertions:

- one regarding the benefits of a 3D Space Syntax analysis digital tool, using for this purpose a case study - the *Casa da Música* in Oporto;
- another, advocating some architectural and urban considerations on the iconic (and controversial) case-study (by Rem Koolhaas, OMA) using, for this purpose, DepthSpace3D - a new digital tool for Space Syntax analysis.

When neither methodology nor its domain of application are well established, many problems of auto and cross false endorsement may arise.

To avoid such questions, validation was attempted by :

- supplying comparative studies using 2D Space Syntax proven methodologies;
- consulting other (non-formal) type of sources, in current architectural discourse and critique;
- gathering and processing empirical data using people tracking and mapping tools.

1.1 SO, WHY DEPTHSPACE3D?

Previous research developed on specific domains of Architectural and Urban Studies (A&US) using Space Syntax by the researchers involved in the DepthSpace3D project has confirmed the value of Space Syntax in the analysis of A&US. Nevertheless, some issues had been detected. For example, the global analysis of the city of Maputo (Viana, 2015) with intense use of Space Syntax 2D tools, could not deal with the problem of Maputo's altimetry. The intensive use of Space Syntax to study segregation and privacy in 13 collective housing enterprises in twentieth century Oporto (Ruivo, 2014) concluded that 3D analysis could improve the results. Although Space Syntax 2D could deal fairly well with the interior of each home and the middle-scale urban environment, it could not integrate the high-rise buildings as a whole in the context of the relation of the building and its near environment, treated as a unique domain of analysis.

At least, 3D tools may demonstrate to be of great usefulness in cases of rough topography of urban spaces; dynamic volumetric geometry: size, configuration, elevation and interpenetration; joint analysis of the interior of each building and its urban environment, in particular when there are high-rise buildings.

1.2 AND WHY CASA DA MÚSICA?

For the following reasons, *Casa da Músic*a is notably suited for 3D analysis:

- its interior space possesses a very intricate volumetry that is impossible to model two-dimensionally;
- a 2D polygon cannot suitably model its exterior surface, a 3D polyhedron;

- the ground of the *Casa da Música* square is moulded in curved surfaces, not prone to flat visibility;
- visibility between the inside of *Casa da Música* and its urban environment is established through a set of non orthogonal windows at diverse heights;
- one of the surrounding squares is filled by a garden with several plant species, at diverse heights.

The development of the research in *Casa da Música* led to the distinction of two different case studies:

- the global volume of *Casa da Música* and its urban environment, with little consideration of its interior; this study deals essentially with visibility analysis;
- the interior of *Casa da Música*, dealing with visibility issues, but also with the shapes and space configuration of the interior space.

2. DATA SETS AND METHODS

2.1. CASA DA MÚSICA AND ITS URBAN ENVIRONMENT

This case study has been modelled in 2D and in 3D. The 3D model has some conceptual and operative differences from the 2D that are worth to be elucidated.

a) delimiting the case study

The first necessary operation was to geographically delimit the case-study within the globality of the city's urban space. 3D visualization must be taken in account when performing this operation, in order to avoid the 'disappearance' of sections of the environment that can affect the results. Possibly, some issues cannot be predicted solely through a 2D plan.

The case study considered a geographical delimitation encompassing the two squares (Boavista roundabout and *Casa da Música* square) and the first dozens of meters of the confluent streets.

Two issues were reported, although they were not considered:

- the monument in the centre of the Boavista roundabout is visible from a much larger area, but it was not the kernel of the case study;
- the intended visibility of the sea from *Casa da Música* (that, at least, provoked the public controversy around the "hole" in the EDP building), would require a 6km analysis through a dense urban space.

b) three conceptual spaces: the viewing, the viewed and the obstacle spaces

The 3D conceptual model predicts three diverse conceptual spaces: the viewing space, the viewed space and the obstacle space.

The **obstacle** (to visibility) **space** is modelled by the surfaces of:

- the exterior of the volume of the *Casa da Música*; the interior is depicted by a minimum number of interior walls; some of the large windows are declared totally transparent (using a feature of DepthSpace3D);
- the facades of the buildings of the Boavista roundabout and the neighbour streets, since volume representation would not bring significant difference;
- the ground,whose only relevant topography is the curved shapes in the *Casa da Música* square;

- the trees in the garden inside the Boavista roundabout - three kinds of trees were considered, as an attempt to model the real diversity of the square: a majority of deciduous trees (with opacity varying from 15 to 80%, throughout the year), some evergreen trees (with permanent opacity of 75%) and palm trees. This led to two comparative studies, one for winter and one for summer conditions;
- the monument in the middle of the roundabout, a statue in a very high pedestal which is a distinctive historical monument of Oporto.

The active space for 2D analysis had to be divided in two conceptually different spaces in 3D. Contrarily to what happens in 2D analysis, the viewing space and the viewed space are not the same. For example, because it is unusual for people to fly, the **viewing space** - the space where the viewing subjects can move - is different from the totality of the studied volume. In this context, five different instances have been studied, resorting to DepthSpace3D's possibility of modelling many visibility paths:

- the cars, at 1m height;
- the pedestrians walking in the interior garden of Boavista roundabout, at 1,5m height;
- the pedestrians walking in the *Casa da Música* square, at 1,5m height;
- the windows of the buildings, at several heights;
- the windows of *Casa da Música*;
- as DepthSpace3D also enables composite paths, two other were considered relevant: the global pedestrian path (composed by pedestrians in the Boavista roundabout and pedestrians in the *Casa da Música* square) and the global path (union of all the paths).

Something else must be said about the viewing space:

- the paths are discretized in a small number of viewPoints - intense use of the DepthSpace3D software has proven that a very large sets of discrete points brings computational performance issues; fortunately, a smaller set of viewpoints lead to very similar results to those obtained with a larger set.
- each View Point has its 'volume of influence' (the volume of the part of the space represented by each viewpoint). They are also charged with a "weight", a calibration number that makes it possible to consider some other conditions. For example, the viewpoints of the car's path have a lower weight than those of pedestrians, considering:
  - the density of people in cars, against pedestrians density;
  - the lack of visibility from inside the car;
  - the minor attention paid by drivers to their surroundings.

The **viewed space** has two components:

- the urban surfaces; although conceptually different, they are physically identical to the obstacle space;
- the global volume, the surrounding 'air' that is modelled by a grid.

2.2. THE INTERIOR OF CASA DA MÚSICA

In the exterior, only visibility studies were considered. In the interior, besides visibility, this paper also attempts to study space semantics. While this doesn't bring any additional question in 2D analysis, where there is no conceptual identification of the problem (they are both achieved through the same tools), in 3D analysis, as we will see in c), this brings further issues.

a) delimiting the case study

The section of space considered in this case study is strictly the interior, delimited by the exterior walls. The relation between interior and exterior is studied in the precedent case.

b) three conceptual spaces: the viewing, the viewed and the obstacle spaces

When studying visibility, the three conceptual spaces remain the same. The obstacle (to visibility) **space** is modelled by the all the surfaces of the exterior and interior (walls, floors, columns and other elements) of the *Casa da Música*. The **viewing spac**e is the space where people can walk. The paths of the model are:

- the spectators path
- the staff path
- the visitors path

The **viewed space** has two components:

- the building surfaces, physically identical to the obstacle space;
- the global volume, the "air" that is modelled by a grid with 2m interspace.

c) the metamorphoses of the conceptual spaces

This is valid when considering visibility. What about space semantics? The surfaces are not obstacles to visibility, but the boundaries that establish the limits of and between volumetric (and two-dimensional) shapes. We could call it the **shaping surfaces**. This viewing space only concerns visibility studies. Space configuration studies don't use this data. The concept of viewed space also disappears.

The global **volume** is not viewed but is shaped by the shaping surfaces. There is also a change in the measured quantities. In visibility analysis, the base quantity is the visibility, the scalar function (that has values between 0 and 1) that relates all the points of the viewing space with the all the points of the viewed space. In space semantics, the relation is between any two points of the global volume and can take the value of 0 or 1, depending on the possibility to draw a straight line between them. Although the involved math is the same (visibility between two points is also given by a straight line) they can not be conceptually mixed up.

3. RESULTS

3.1. URBAN IMPACT

OMA's *Casa da Música* is located in a highly integrated area of Oporto, marking the beginning of an important axis which, extending 7km west, connects the city's centre to the seashore. The project was developed within Oporto's nomination for the European Union's programme European Capital of Europe, and both its location and function came following a strategy of cultural enhancement of Oporto's west, which had been reinforced by the development of a contemporary art museum and City's park between 1993 and 1999.

Figure 1 - *Porto's axial map*

The roundabout where it is located was built between 1866 and 1892, appearing in the context of an expansion of Oporto's public transportation, and would contribute for the establishment of a new centrality in the City.

From here, the development of a new urban axis, finished in 1915, allowed urban growth towards the ocean and contributed for the residencialization of an area that was previously un-urbanised and in the process of de-industrialization.

In the beginning of the 21th century this process was still not over, and, while the newly developed subway again helped establish this area as one of the better connected in the city, stressing it as an important centrality, the Boavista roundabout was still not completely defined, punctuated by derelict plots such as the one where *Casa da Músic*a was built.

While the target of heavy criticism at the time, the construction of the iconic building came integrated in an urban strategy in place from the 19th century. Located in an area which, however vital for the City's reconfiguration and for the establishment of a new centrality, was still undergoing a process of de-industrialisation and subsequent tertiarization, the *Casa da Música* was meant as a new pole of activity and urban attraction.

The part it played in both in an "internationalization" of the City (Tejada, 2016) and in the development of new, large scale equipments in the surrounding area has been discussed in the past years. To approach this question, the paper will focus on the building's impact on its urban surroundings, resorting to three-dimensional analysis software.

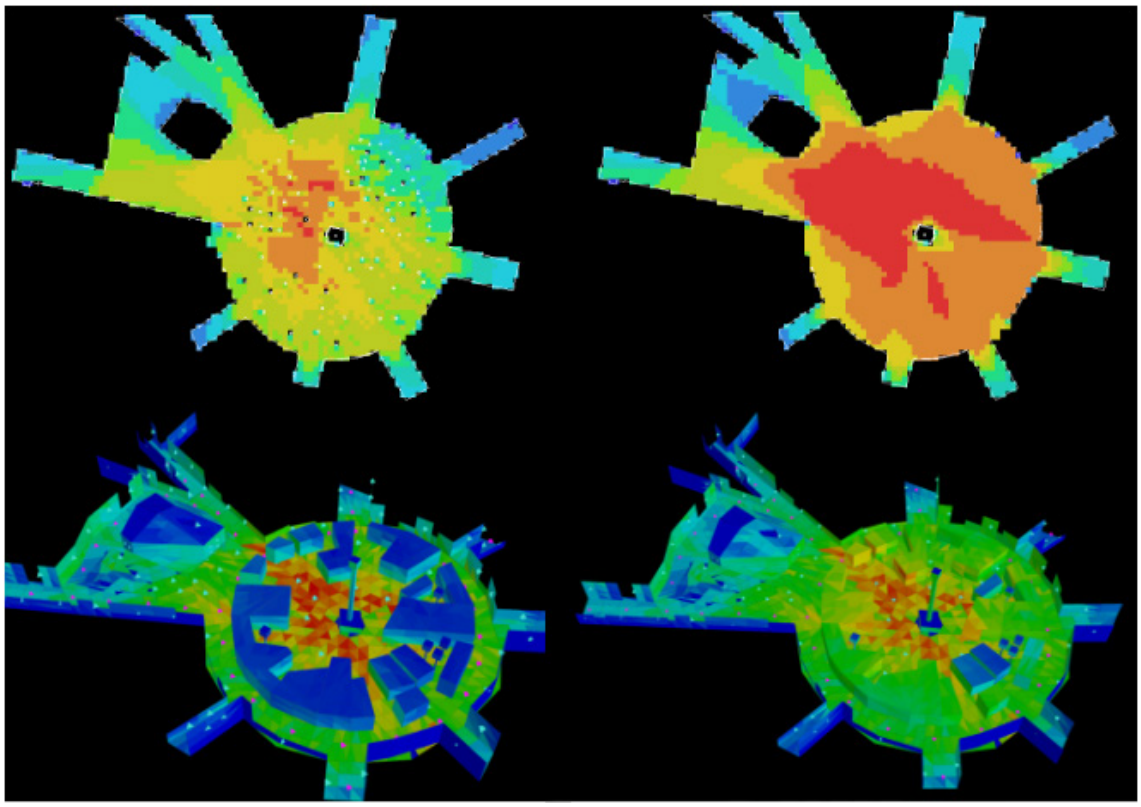

Figure 2 - Boavista roundabout and CdM's public space, limited by the surrounding buildings' facades. Visual connectivity values in 2D (with and without trees) and 3D analysis (different transparency values on treetops for Summer and Winter months).

While there are enough similarities between a two-dimensional and a three-dimensional visual connectivity analysis of the studied space to validate the obtained results, some differences should be noticed. In both cases: the most connected area is the part of the roundabout located in front of the *Casa da Música*, with values getting lower towards the surrounding buildings

and adjacent streets. However, it is interesting to verify how the trees in the square have an important impact on the visibility of the entire area, and how this translates to a three-dimensional analysis. On the one hand, it was possible to attribute different transparency values to treetops, representing their visual permeability during Summer and Winter months, and conduct two different analyses to understand how the connectivity values of the studied area shift throughout the year.

Then, it is also of note that even though a two-dimensional analysis is able to capture the visibility values for the periods when the trees are leafless, these cannot be read as corresponding to the associated facades. Due to the diminished visibility caused by the treetops, a distinct loss of perception of the buildings surrounding the roundabout could be verified through a three-dimensional analysis.

Taking into account the controversy generated around the construction of the new music hall, this is of particular relevance for the present study, as it allows for a more complete understanding of *Casa da Música's* presence and impact on its surroundings. If the iconic character of a building designed by a foreign star-architect, distant from local architectural tradition, seemed to easily attract wary comparisons to Bilbao and the Guggenheim effect (Ramalho, 2012), it seems to be difficult to argue that it causes any relevant disturbance in the existing city fabric. While the objectual nature of the project seems clear, the *Casa da Música* isn't granted a monumental status by its surroundings, presenting connectivity and visibility values not distant from those of the other buildings surrounding the roundabout. It is interesting here to draw a comparison between the requalification of the roundabout's garden and that of Oporto's City Hall avenue, both taking place during the period of intense urban regeneration which integrates the construction of the *Casa da Música*, and both authored or co-authored by architect Álvaro Siza. It is curious how the approach to existing vegetation and trees is strikingly different in both cases. In the same way its preservation seems to have great influence in the way a building such as *Casa da Música* is perceived - or not perceived - in the City, its complete removal from the avenue leading up to the city hall seems to reinforce the monumental and institutional nature of that space.

Volume attributes were used to explore this question further, both concerning *Casa da Música* and the monument for the heroes of the peninsular war located in the center of the roundabout. A noticeable issue, that highlights a special feature of DepthSpace3D, is worth to be reported. The historical monument in the centre of the roundabout appears in the Space Syntax analysis as a less visible object. But this is a misunderstanding of the conceptual framework of the performed analysis. The monument is not an explicit object in the model. The explicit objects are the surfaces of the monument. And each surface is seen by not more than half of the viewing space. In order to approach the model to reality, DepthSpace3D has a feature that consists in assigning attributes to sets of objects.

We can construct a new concept in the language - the monument - as a set of the primitive concepts: surfaces or points. And finally, we can see the visibility of the new object, an aggregation of all its primitives. This feature can easily extend from physical entities to abstract concepts.

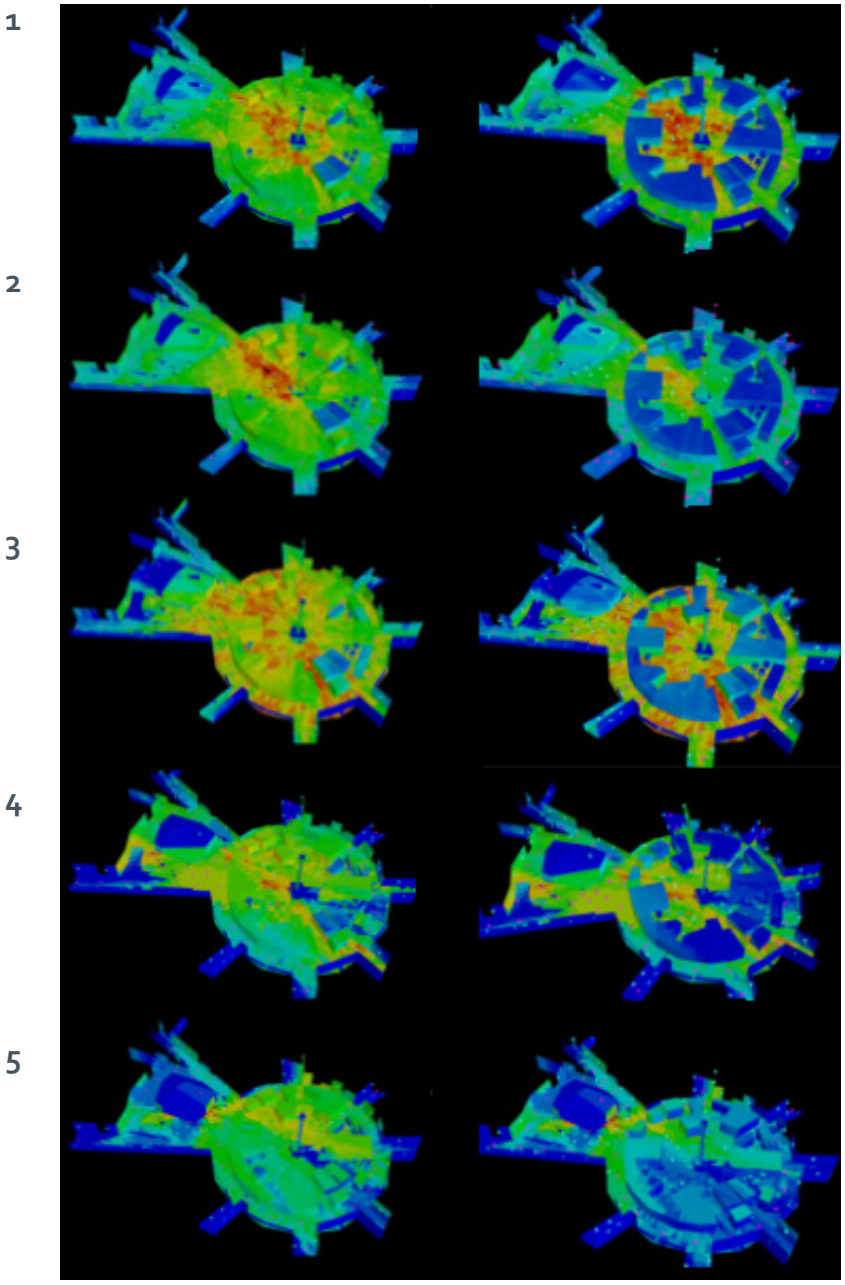

Figure 3 - Different paths showing different visibilities for Winter and Summer months (1.cars, 2.windows,3.pedestrians in roundabout, 4.pedestrians in square, 5.Casa da Música's windows).

Path analysis also seems to confirm that *Casa da Música's* impact is most felt from the public space resultant of OMA's intervention.From these it was possible to verify that the roundabout's garden is the most visually connected area and that, even though *Casa da Música's* public space is highly visible from its inside, the building is not. It is mostly seen from the surrounding buildings, whose different heights allow some of them to look both over the trees and other buildings, and by pedestrians on OMA's designed public space. Visual contact between *Casa da Música* and the exterior is also limited from the inside, with its large windows not allowing for a good perception of the exterior space. Even though, bi-dimensional analysis also allows for the study of different paths, the possibility of concatenating them in various groups, as well as attributing them different weights, contributed greatly for this analysis.

3.2. PUBLIC SPACE

Regarding public space analysis it was structured a methodological process combining the composition of a computational code (able to use tracking approaches with OpenCV) and data mapping to visualize space appropriation densities and intensities, defined by local and daily space users. Data visualization was developed through thermic maps and cumulative isocurves maps, that reveals main walking patterns concerning people's space dynamics and interaction within *Casa da Musica* surroundings.

The methodology set to study the public space was based on a three steps strategy involving video tracking, pattern recognition and dynamic mapping. After these phases, the information resulting from data collection and visual analysis methods was confronted with the outputs from DepthSpace3D, in order to verify its convergence with empirical analysis. Data extraction was possible due to the implementation of a pattern algorithm into Python, using OpenCV libraries, such as those used to computer vision (Computational Biometric) initially developed by Intel in 1999, that includes basic algorithms to people recognition. It is an open access library under BSD licence. The recognition process occurs due to an algorithm that removes video's background to get pattern's outline, through which sets a rectangular frame needed to track the movement in every video snapshot. The outcome of this process is an image full of dots concerning individual movements traced on the space (Figure 4).

Those dots extract from Python compose a file .TXT with rough personal space appropriation data regarding people's walking trends and spatial main tendencies structured within X and Y cartesian coordinates of the resulting grid from video processing. After this phase, the dots conversion process implies the use of a Rhinoceros plug-in called Grasshopper. It was then possible to proceed to data management collecting elements to set the main space appropriation patterns and produce information regarding people's dynamics and space interaction within *Casa da Musica* public space and its surroundings.

The thermal maps developed to *Casa da Musica's* space public analysis were structured to achieve space uses intensities visualization able to show the different kind of space densities attached to *Casa da Musica's* surrounding area. It was important to understand how that space was occupied within several space-time frames. These maps provided a range of colours between blue and red that translates the most used spaces (red) and those with less human fluxes and trajectories. One of the main constrains of these kind of maps is the difficult to extract a clear individual visualization, where one can identify single paths and space appropriations. To suppress this limitation, it was developed a set of isocurves maps resulting from graphical computation approaches. The main goal of the use of this kind of data visualization was to get individual space occupation patterns defined by proto-geometries, that expresses people's space dynamics and its convergence into collective spatial intensities, also through a wide colour range implying different space performances and group space sensitivities.

On the other hand, the cumulative isocurve maps were based on the accumulation of dots extracted from different mapping methods and its articulation with the same kind of algorithm used on step one of the process, when defining the isocurves maps ("metaball"). The algorithm makes the isocurves as an average result of the distances between every points. It was possible to get cumulative isocurve maps regarding *Casa da Música's* public space, where one can observe distinct space densities which reveals how *Casa da Musica's* surrounding area pulse and establish links to other parts of its neighborhoods and the City in terms of paths' continuity, visual connectivity, overall and sectoral visibility performance. To achieve it, it was necessary to complement *in situ* survey and empirical approaches/video tracking with formal methods (Viana, Franklim & Vaz, 2015) like the one provided by DepthSpace3D.

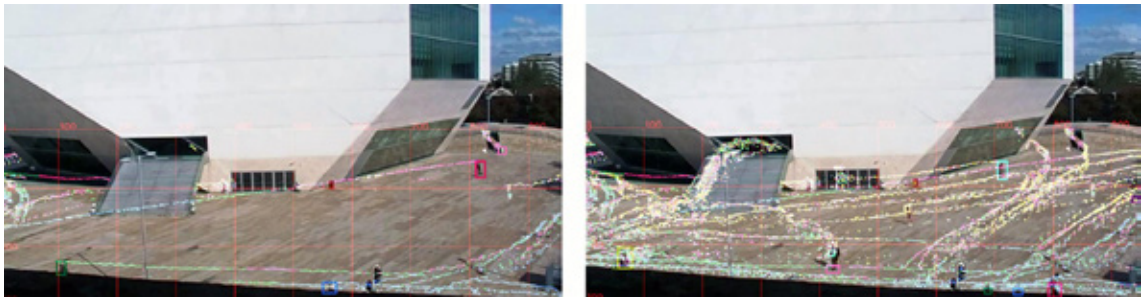

Figure 4 - Tracking space dynamics and individual paths using video and computational/digital methods to capture personal appropriation and fluxes within *Casa da Música*'s public space.

When analysing *Casa da Musica's* surroundings it can be said that the spatial relation between local visibility and patterns paths have similar performance. For instance, Figure 5 shows (for Winter time) the main crossing area between *Casa da Musica's* square and Boavista roundabout. It reveals the interdependence within the transitional space promoted by *Casa da Musica* roundabout facade and the less presence of trees within the zone.

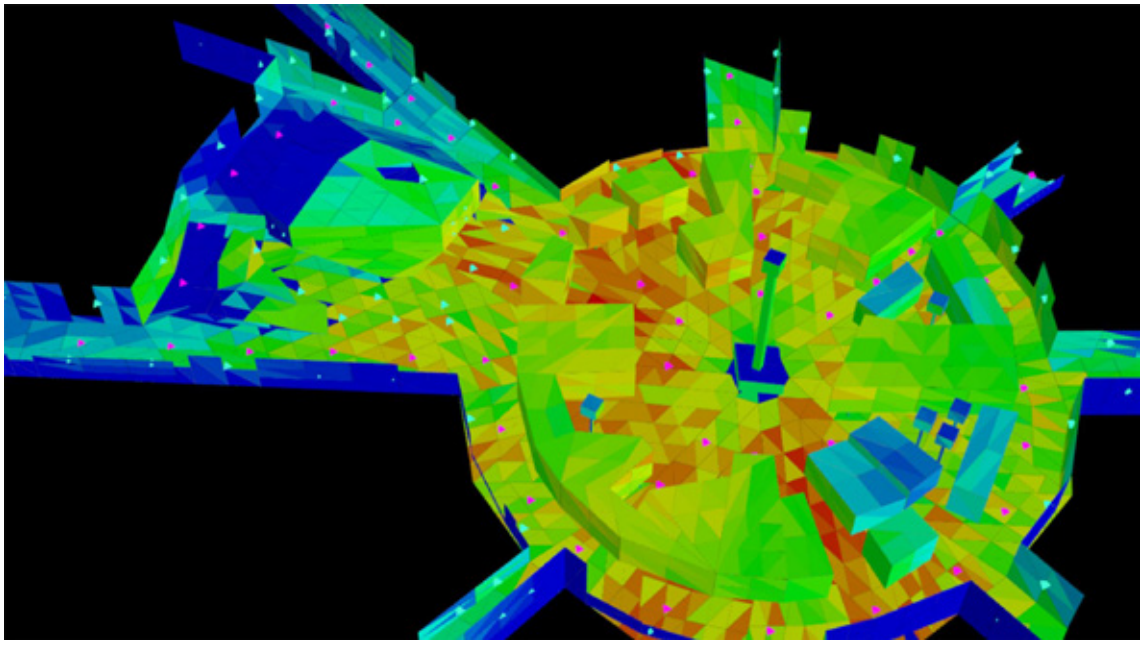

Figure 5 - DepthSpace3D visibility analysis of Winter time, with visibility points and viewed surfaces, where it is possible to verify where people tend to cross to *Casa da Música's* square.

If one attend Figure 6, it possible to check that the result provided by DepthSpace3D to Summer period also maintain the same area as one with best visibility performance. It is important to confront Figures 5 and 6 with people's space dynamics visualization to understand how individual and collective approach is made to *Casa da Música*.

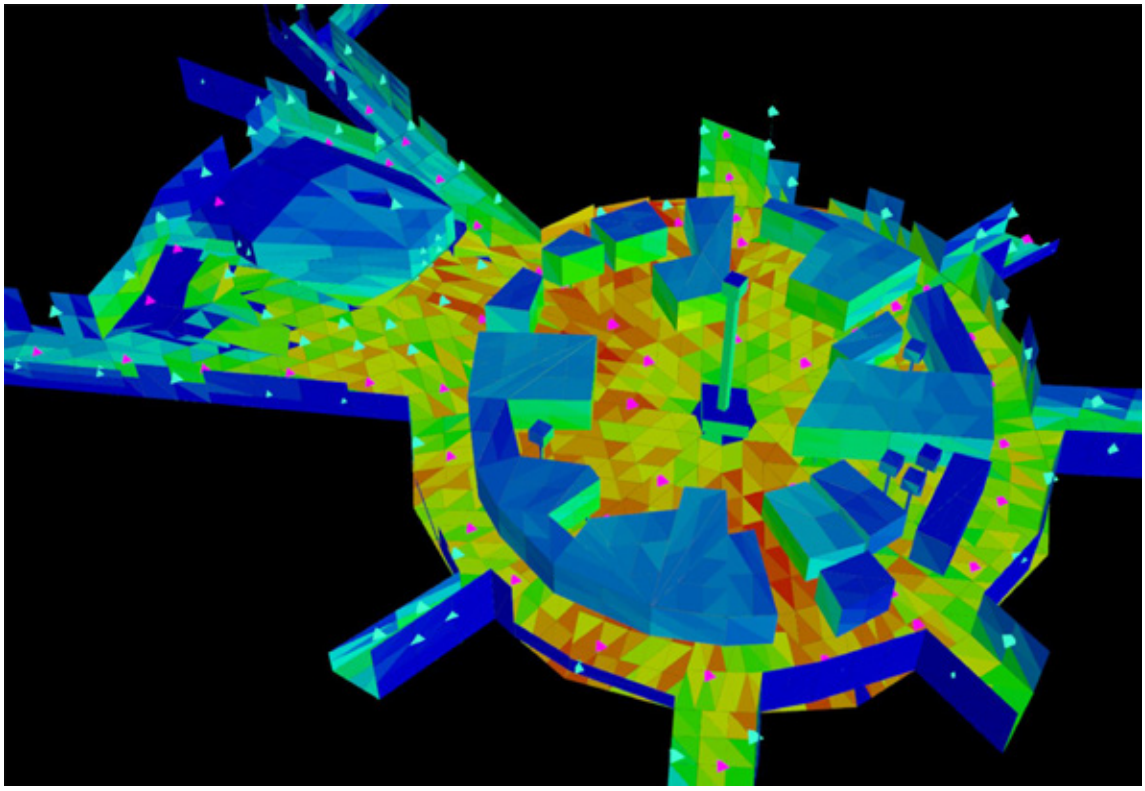

Figure 6 - DepthSpace3D visibility analysis for the Summer period, with visibility points and viewed surfaces, involving the spatial relation between Boavista roundabout and *Casa da Música's* surrounding public space.

Another important aspect, as already mentioned, is to know the type of "pulse" that characterizes *Casa da Música's* surrounding public space. Therefore, let's go back to the already interconnected referred notions of density and intensity. According to Figure 7, the major part of the maps with colorful areas occurs in the main accesses to *Casa da Música's* square The isocurve map reflects how influential those spaces are regarding entering into Casa da Música's surrounding public space. The main entrances to *Casa da Musica* also have an important role concerning this result (Figure 7).

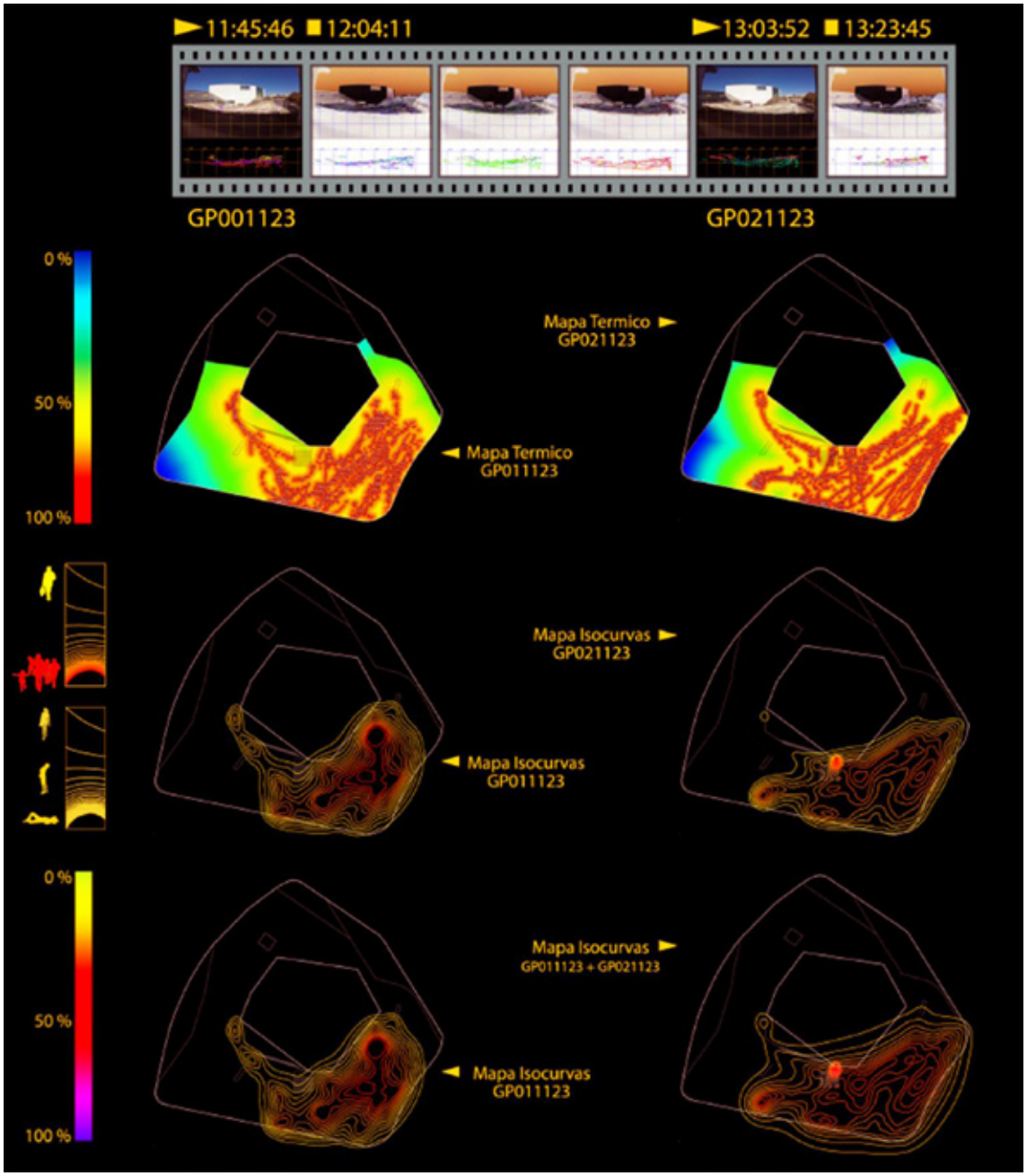

Figure 7 - Thermal and isocurve maps of *Casa da Música's* public space in a Winter day.

Regarding local intensities, Figure 8 shows that the main tendencies sets into intermediate areas that one can find between the principal entrance areas to *Casa da Música's* surrounding public space. From these sort of results it is possible to say that it is more relevant to people's local spatial uses and appropriation the sensitive dimension of the space rather than how it is perceived.

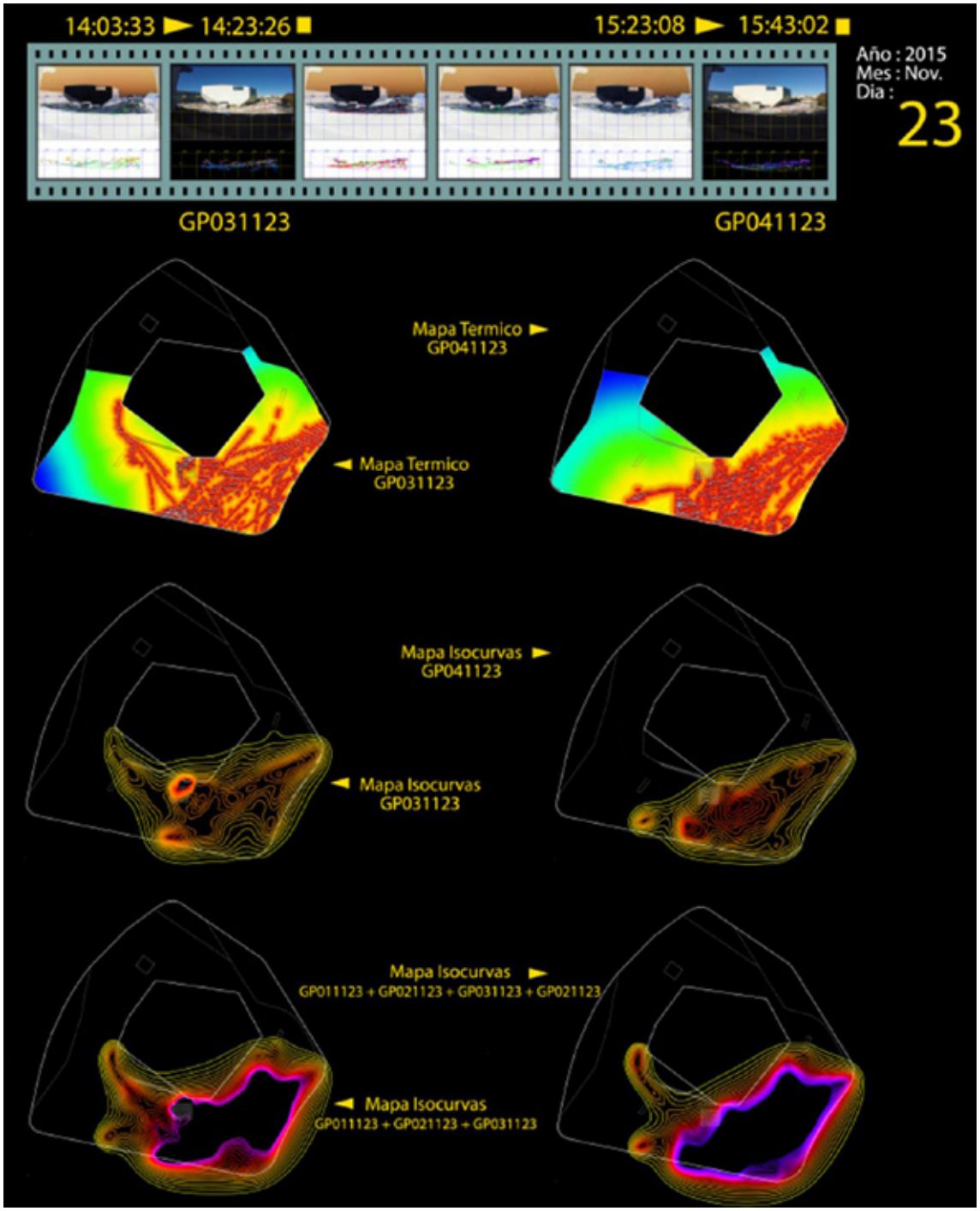

Figure 8 - Empirical tracking, data digital visualization and computational analysis of *Casa da Música's* and scripting to verify the convergence between intuitive approaches, qualitative and quantitative methods, space sensorial qualities and space body experience and perception.

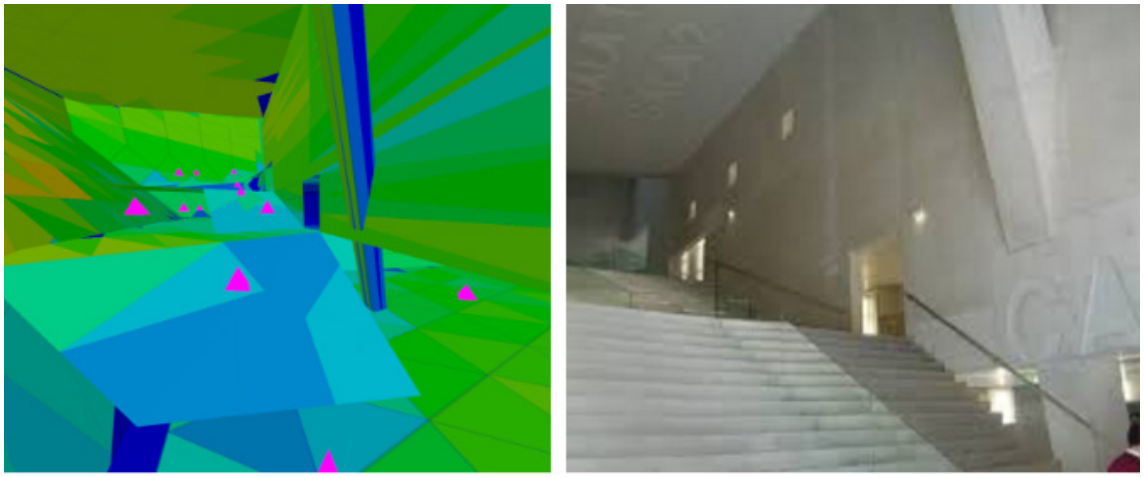

Figure 9 - Connectivity of Casa da Música's entrance hall and main staircase, with photograph for reference.

The complexity of OMA's building poses a challenge for the analysis of its interior spaces. Justified graphs are clearly useful for the systematization of the existing spatial relations, but traditional analysis through axial, convex and visibility maps proved both difficult to achieve technically, and risked being unreliable in translating the entirety of *Casa da Música's* spatial intricacy.

While it seems possible, if not practical, to study the social relations taking place inside the building through two-dimensional analysis, three-dimensional tools seem essential for getting a full grasp of the total complexity of its interior. As Figure 4 makes clear, using space syntax methodology for the analysis of the formal qualities of space and, for example, for an analysis of style, can greatly benefit from three-dimensional tools.

In this particular case, three-dimensional tools allowed for certain observations regarding Koolhaas' architecture, confirming design patterns and spatial qualities proposed in previous Space Syntax analysis of his work. (Dovey and Dickson, 2002; Zook and Bafna, 2012).

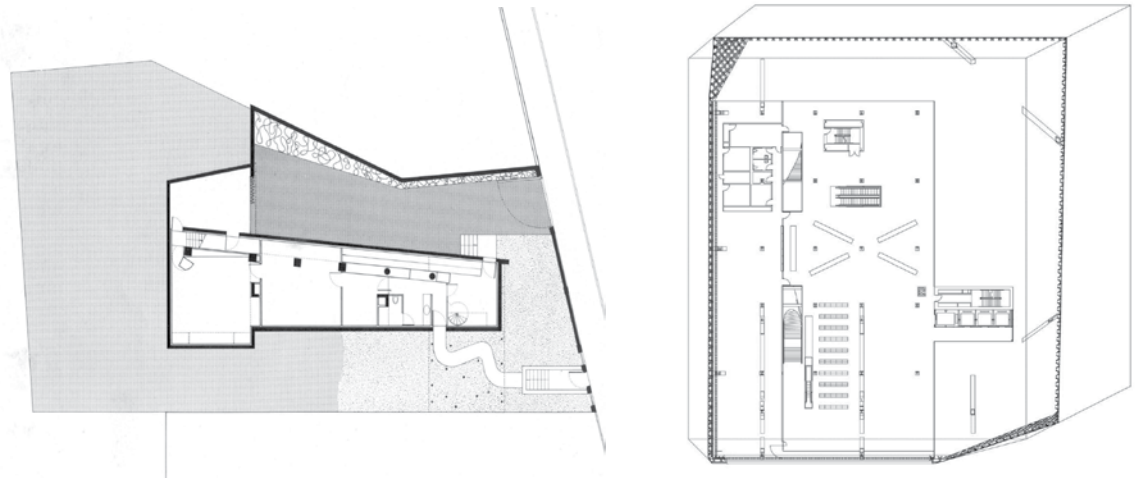

Figure 10 - Multiple vertical accesses in Villa Dell'Ava and Seattle's Public Library, by OMA

The multiplication of accesses seems to be a characteristic transversal to most of Rem Koolhaas work, from small scale to large complex buildings, resulting in the production of particularly shallow structures, with spaces highly connected between them and presenting low levels of control. In *Casa da Música*, there is a clear division in this aspect between private (such as

administration and services) and public spaces. While it doesn't follow the traditional structure of control where shallower spaces are allocated for visitors and deeper spaces for employees (Markus, 1993), private spaces follow a tree-like hierarchy of corridor-functional area, versus highly "ringy" public areas. In the latter, with the exception of the two concert halls and the restaurant on the terrace, there is little differentiation between programmatic areas and circulations.

Presenting no dead-ends (with the exception of restrooms), functions are integrated in a succession of ambiguous spaces and the resulting configuration seems to follow the same logic as described by Zook and Bafna (2012) for Seattle Central Public Library, were the building "enhances incidental movement into attraction spaces while limiting such ingress to the functions" (p.4). In fact, the two concert halls - easily the most important functions of the building, are accessed through contrived routes, while the ampler and better integrated spaces are often not associated to any official program.

The narrowness of the foyer gives it a very circulation character which, added to the greater integration of the large staircase shown in Figure 4, results in a shift of the foyer's original function to this space. The largest views, even though low control and poorly integrated spaces make it impossible to perceive the globality of the space from within the building, are usually possible from more segregated, almost "accidental" spaces.

4. CONCLUSIONS

The paper presents a new digital tool, DepthSpace3D, with its own theoretical background, methodological framework within formal methods (adding a 3D operational interface to visibility and configurational space analysis), and - through the application of this new digital tool to a real case study - it was demonstrated the potential of its semantic context and syntactic structure. Even as a brief induction to DepthSpace3D, the paper go forward to new possibilities to converge empirical space analysis based on video tracking and dynamic mapping with quantitative methodologies, narrowing the gap among each other. One of the main idea of the research is to set a wide platform of existing and new digital tools applied to Architecture and Urbanism able to work together within a combinatory and integrated design process, where analogical instruments can be complemented with computational languages and technological development in data collection, management and visualization, space information analysis, collaborative and shared design processes and participatory projects.

Space and data, formal methods and DepthSpace3D, community engagement and mapping, are being put together in a relational methodology in order to deepen the knowledge regarding people/space dynamics, flows and interaction, considering this equation on its multidimensional layers of transdisciplinary existence. The interoperability and proximity between different languages will put us closer to higher levels of hybridization, dialog and interoperability among several digital platforms and tools. DepthSpace3D looks forward to fulfill this mission. To do so, and regarding future steps, the ongoing research will set actions to put DepthSpace3D into the market with capacity to be not only an autonomous digital tool, but also to be part of existing ones - complementing and adding new features to the design process.

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