

# Unreal Reality: An Empirical Investigation of Augmented Reality Effects on Spatial Cognition in Landscape Architecture

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**Abstract:** Augmented Reality (AR) has experienced over the last years considerable technical improvements and an important increment on its use by a diverse range of users, as a result of its application through handheld devices like mobile phones and tablets. This situation has made AR a relevant and accessible instrument for the visualization of virtual spaces merged with the real world. Within the field of Landscape Architecture, AR has several potential uses in the areas of design, education and public participation. The premise of this research is that AR, through the spatial visualization, the exploration and the provision of meaning of augmented spaces, works as a tool to assist and enhance the spatial cognition of users, setting a new step in the traditional ways of reading the landscape. To support this premise, a practical exercise using handheld AR to experience a Landscape Architecture design located in an outdoor environment was applied, considering and comparing three scenarios of exploration. In these scenarios, viewers experienced different combinations of degrees of freedom (DOFs) to observe the intervention. The results showed that users perceived exploration as a positive aspect, that they successfully provided meaning to space, and that they were able to describe the spatial relations within the AR intervention with distinct levels of accuracy, depending on their scenario of exploration.

**Keywords:** Augmented reality, handheld devices, spatial cognition, landscape architecture, degrees of freedom.

## 1 Introduction

Augmented Reality (AR), defined as “a technology that mixes the real environment with the virtual, is registered in three-dimensions, real-time, and interactive” (AZUMA 1997, as quoted by LIAO & HUMPHREYS 2015), allows the visualization of computer generated information, such as 3D objects, merged with the real environment. Despite existing since decades, AR has been spreading at a fast pace in the last years because of major technical improvements in its performance and accessibility, in hand with the significant expansion of handheld mobile devices such as tablets and smartphones, that work as media for AR applications. These circumstances have made AR the new lens with which people can read the landscape. Bearing in mind that more than 80 % of the perception, learning cognition and interactions with our surrounding come from sight (POLITZER 2016), the study of this technology attracts the interest of many disciplines related to the relation between people and space. Considering the scenario illustrated, the connection with Landscape Architecture automatically appears, as well as questions about what aspects of and how Landscape Architecture would be affected

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by this new technology. The main arguments for the justification of this research relate to three aspects:

1. The popularization of handheld mobile devices as platforms that bring AR content to the public (VEAS & KRUIJFF 2012), together with the increasing time that people spend on these devices since the last decade (COMSCORE 2017).
2. The potential that AR brings into the discipline of Landscape Architecture
  - in the areas of education, as a learning tool to accelerate spatial cognition processes,
  - in the professional field, as an experimental research or design instrument, and
  - in the public sphere as a communicational tool to bridge spatial representations and foster common understanding between different stakeholders.
3. The lack of empirical research done to analyze how people are engaging, perceiving and using AR, in order to understand the ways this technology affects the mental spatial constructions (NISHA & OLNEY 2017), which is particular to each person and represents the key factor to reach common understanding on many of the decisions that professionals must face in the field of Landscape Architecture.

These aspects support the idea of AR as an accessible tool, competent in different areas within Landscape Architecture, but still lacking of a full comprehension of its impact on people's use of the technology. In this matter, the implications of AR on the process of Spatial Cognition appears as an interesting phenomenon from the perspective of Landscape Architecture, understanding this concept (Spatial Cognition) as the process with which humans navigate, interact and communicate about and through space (LANDAU 2002). Therefore, the understanding of AR consequences on spatial cognition in a theoretical but also practical way, occurs as a necessary preceding step to its full deployment and integration into the discipline of Landscape Architecture.

## 2 Research Objective and Hypothesis

Considering this background, the main objective of this research is to understand how the exploration of a Landscape Architecture design through handheld AR affects user's spatial cognition. For this purpose, this investigation considers certain relevant variables contained within handheld AR. Among these, the qualities of visualization and movement that a handheld mobile device offers represent an important factor that determine at what extent the viewer can move through an AR scene and how much of it can be seen. These possibilities of movement, defined as Degrees of Freedom (DOF), refer to the different rotational and translational possibilities of movement that an object or an observer can perform in space. The hypothesis of this research is that the additional DOFs provided during a handheld AR experience (full rotation and translation movements of the viewer through the scene), will constructively affect the spatial cognition of a landscape architecture intervention in terms of spatial visualization, exploration and provision of meaning of space; on the other hand, the fewer degrees of freedom allowed during a handheld AR experience, will result in a lower and limited spatial experience, conditioning the user's spatial cognition of the intervention.

## 3 Literature Review

### 3.1 Spatial Cognition

According to the American Psychological Association (APA), spatial cognition is defined as a sub-area within the cognitive psychology field, which studies “how people acquire and use knowledge about their environment to determine where they are, how to obtain resources, and how to find their way home” (WALLER & NADEL 2013). Since we are born, the development of Spatial Cognition along our lives is fed by our experiences, subsequently determining the way we read the landscape and how we interact with it.

Although many other senses are involved in this process, sight represents between an 80-85 % of the perception, learning cognition and interactions with our surrounding (POLITZER 2016). Sight is one of the first steps to build spatial cognition in children, however the development of motor capacities like crawling and walking leads to another level of cognition. Through this new ability of exploration, children jump into another level of experiences by interacting with more freedom with places, objects and people, increasingly learning more about the world around them and about the affordances of interacting with it (GIBSON 1988, GIBSON 1979 as mentioned by MULDER et al. 2016). In more advanced stages of spatial cognition, spaces gain meaning and turn into places; for a child then a park becomes a place where people can go with their pets to walk or climb trees, and where a playground area exist, children assume that there they can play and interact with friends. Through more advanced levels of exploration, which implies the use of senses plus the ability to move, we can build a deeper understanding of spatial configurations as well as of the relations between objects and people, execute actions and communicate through and about our context.

### 3.2 Exploring the Landscape

As well as in the case of children that expand their learning about their environment when they start walking (MULDER et al. 2016), AR represents a leap for Landscape Architecture in the ways that people normally explore, interact and understand with space. Among the characteristics of handheld AR, its mobility and attachment to the real world are two qualities that strengthen its usability as a tool to explore the landscape. Through AR exploration users can discover and understand more complex spatial relations between elements, added information and potential changes to existent spaces than the ones we can traditionally see in a 2D visualization. This allows people to see new functions and affordances between objects and space, providing or modifying meanings and uses that finally have the potential to transform a space into a (new) place (TUAN 1977). AR allows users to see and experience these complex spatial relations in imagined yet physically inexistent augmentations attached to the real world, since the relation between place and people is not just physical but abstract and related to our experience (LYNCH & HACK 1984).

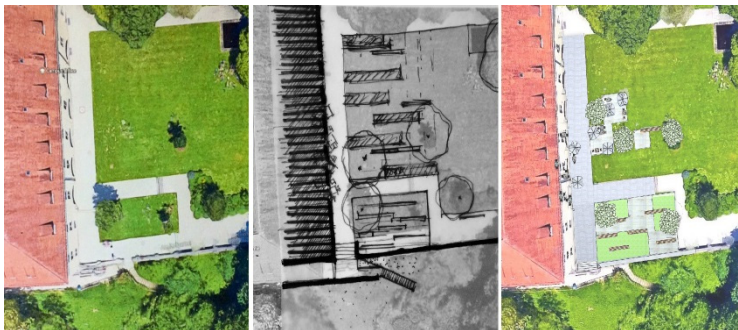
During the research process, different experimentations with AR showed the capacity of this technology to offer a new perspective of immersive virtual spaces overlaid onto the real world, providing several possibilities for the mobility and observation of the viewer. Alterations in the user's spatial visualization, exploration and provision of meaning of an augmented landscape design emerged as possible symptoms of a handheld AR experience. The spatial relation between the observer and his context results critical, as well as the DOFs that

he or she can enjoy in that interaction. The possibilities of looking around and using peripheral and foveal vision to focus on objects of attention result crucial to the landscape experience (DANAHY 2001), and handheld AR can be a tool capable of providing these options.

The concept of DOFs refers to the range of possible movements that an observer can do, composed by six different types that can work together in multiple combinations. These six types of movement are classified into two groups, translation and rotation. Within translation, there are side to side motion, vertical motion and closer-further motion, meanwhile in rotation there is yaw, pitch, and roll (LAVALLE 2015). These degrees of freedom are within our daily actions, e. g. when our head and eyes rotate while walking forward or in lateral displacements through the public space, and the combination of them help our different sense organs to gather the necessary information to perform our tasks. In the case of AR, the use of an accessible handheld device such as a mobile phone allows users to achieve the six different DOFs. This means that an augmented landscape can be explored in situ, when an AR project is designed to be experienced through a mobile device and the technical requirements meet the case.

### 3.3 Bridging Spatial Understanding

One of the main abilities that people related to spatial-professions such as Architecture, Design or Landscape Architecture enjoy is a high level of spatial visualization. This concept is related to the capacity to envision and manipulate 2D and 3D objects and spaces through mental images, and they are heavily active during stages of design, when solving spatial problems, while manipulating instruments, walking or doing sports (NISHA et al. 2017). The skill of each person on these processes depends on the experience in their use, and it can be more or less developed independently of the age of the individual. However, this gap between designers and ordinary people is one of the main obstacles when trying to create a shared understanding and vision of landscape architecture designs, affecting participation, consensus, and decisions. With the use of AR, this gap can be shortened by complementing users' spatial visualization, providing clarity, insight and design understanding to people (AUKSTAKALNIS 2016).



**Fig. 1:** Aerial view of the location of the experiment (left), of the process of design of the AR intervention (center), and of the final 3D model of the case study

## 4 Case Study

This investigation was conducted under the case study modality; therefore, the AR intervention implemented concentrated all the investigative attention, since, as indicated by MARRADI et al. (2007), the primary goal of investigations with case studies is to understand these in depth. To fulfill the objectives of this research, it adopted an exploratory-descriptive structure and used the qualitative design as the method of work through the application of a questionnaire and image collection as data collection techniques.

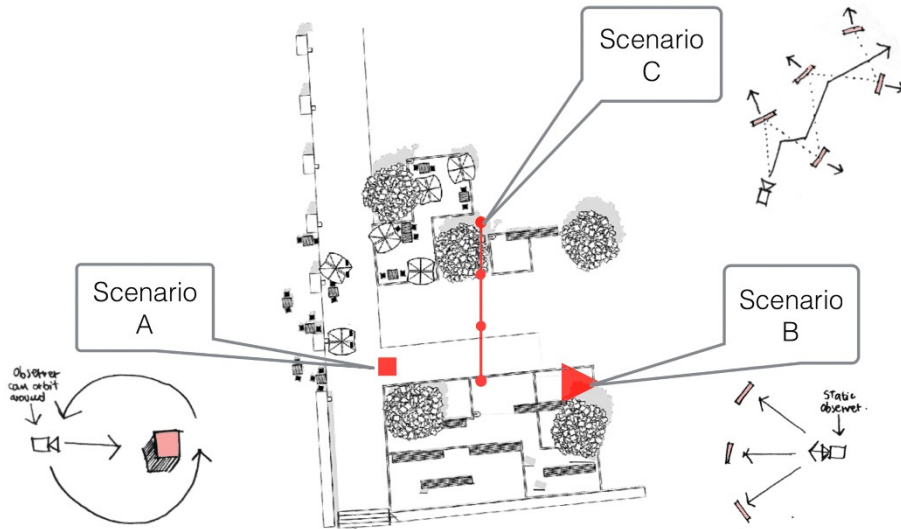
### 4.1 Design of the AR Project

For the design of the AR project, four aspects were defined as necessary to be included within the model. These variables responded to essential characteristics of the main concepts contained within this research, previously discussed:

1. as an AR intervention, it has to be implemented in an existent space, and interact with it,
2. as a Landscape Architecture design, it has to be located in an outdoor location,
3. it has to attempt to contribute on the improvement of the existent situation and
4. it has to allow different scenarios of exploration (combinations of DOFs), to compare how it affects spatial cognition.

With the determination of these four criteria, an outdoor intervention located in a green public space next to a university campus was designed (Figure 1). The AR design considered the addition of new functions such as eating areas through the location of tables and sunshades, resting points through the implementation of benches, modifications in the ground cover textures, circulations, and the addition of vegetation. Three different scenarios of exploration were created, each one with different configurations of DOFs (Figure 2):

- Scenario A: The user can orbit in 360° around the marker. A cube acts as a multi marker, were its different faces activate the augmentation.
- Scenario B: The user can rotate on a limited angle (150°) from a static position with no displacements. Three markers in front of him allow a panoramic view of the AR intervention.
- Scenario C: The user enjoys all DOFs. Several markers are located and aligned in four spots with a distance of 3 m each, allowing to the user to rotate and move from one spot to another in a total sequence of 12 m.



**Fig. 2:** The three scenarios of exploration offered different DOFs of the same AR intervention

## 4.2 Development of the AR Project

The generation of the AR project started with the development of the 3D model with all his components using the 3D modeling software SketchUp. After that, the model file was imported into the game engine software Unity, where with the use of the Vuforia AR plugin, a Service Development Kit (SDK), the augmentation features were added to the project file. Through this SDK, it is possible to activate the function of the camera's device to detect physical markers in the real world that activate the augmentation. This method, called vision-based approach, works by reading images predefined as markers that depending on the angle and distance between them and the camera of the device, make the processor within the mobile phone to calculate the relative pose of the augmentation and locate the 3D content over the real world. The last step is the exportation of the AR content synchronized with the target images, from the game engine software to the mobile device as a test application (App). This is done through the use of a developer software for Apps called Xcode, which works for the operative system selected, in this case iOS (Apple Inc.), due to its stable performance with Unity (SMYKILL 2006), and because of the processor and graphic qualities that these devices present. The mobile device used was an iPad Air 1, screen 9.7 inches, and operating system version iOS 10.3.2.



**Fig. 3:** Pictures of the three scenarios of exploration during application. From left to right scenario A, B and C.

### 4.3 Implementation of the AR Intervention

The AR intervention implemented had an approximate area of 1.000 m<sup>2</sup>, that included vegetation, furniture, ground textures and people, placed in a real outdoor location. For each scenario of exploration, a different system of markers was located through the use of wooden sticks as holders to maintain the images at a proper height, in order to make the experience more comfortable and fluent. It was tested in three different groups of three people each, randomly assigned, attending respectively scenarios A, B and C in different periods of the day each group, one person at a time. The participants were graduate students between 20-30 years old (six women, three men), all of them with academic knowledge in space-design related fields (Architecture and Landscape Architecture), providing a sample group with similar levels of spatial cognition abilities. The academic preparation of the participants allowed a more rigorous test for the collection of data during the experiment.

### 4.4 Data Collection

The exercise activities of the experiment were divided in two stages, first on site to test the app and second inside a classroom where users were asked to draw and answer a questionnaire. The data collected was systematized for a subsequent quantitative and qualitative analysis. The structure of activities in order of application was:

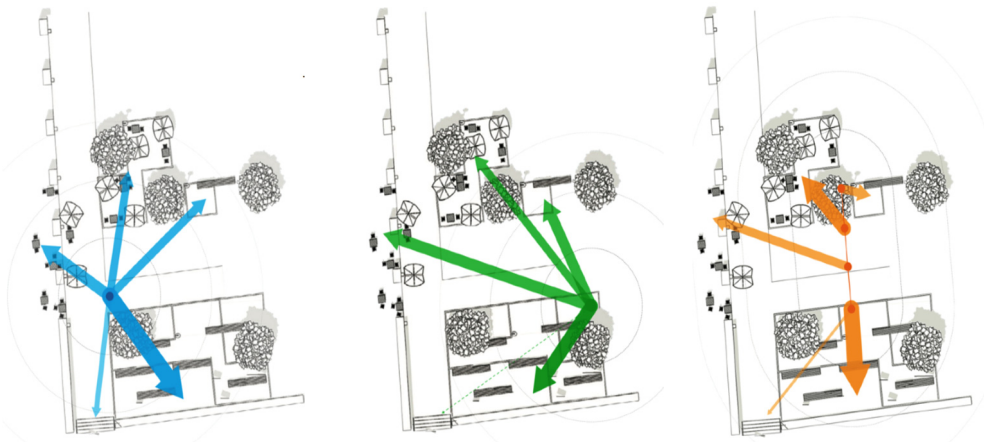
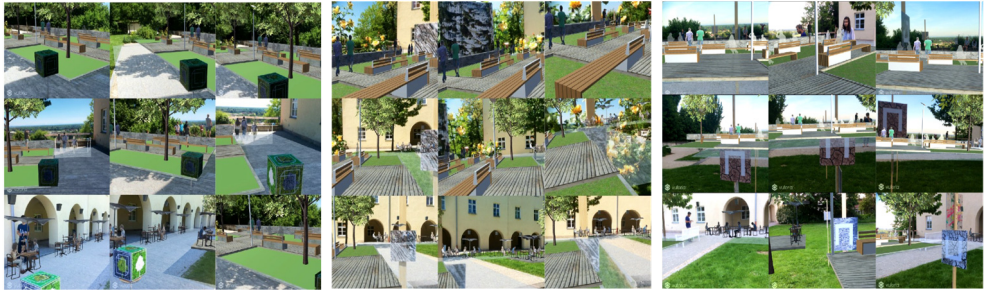
1st stage (outdoor):

- To visualize and explore within a 5 minutes time the AR intervention using the given handheld device.
- To take within the timeframe, five screenshots of appealing views for the viewer, whether for positive or negative reasons. For this, users were taught how to do the operation.

2nd stage (indoor):

- To draw a plan view of the AR intervention, within a 5 minutes time. For this, users were provided with a sheet of paper with some referential lines of existent elements of the project area.
- To draw a cross section of the AR intervention facing the adjacent building (west), within a 5 minutes time. For this, users were provided with a sheet of paper with no referential lines.

To answer a questionnaire of 7 questions within a 10 minutes time, including direct questions related to uses and activities identified within the intervention, to visual perception, to user mobility and to device use.

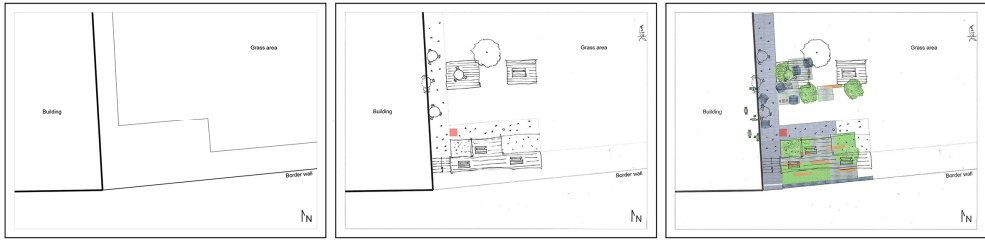


**Fig. 4:** Part of the screenshots collected per scenario and their distribution on the plan view. Arrow thickness indicates high/low concentration of screenshots in each area.

## 5 Results

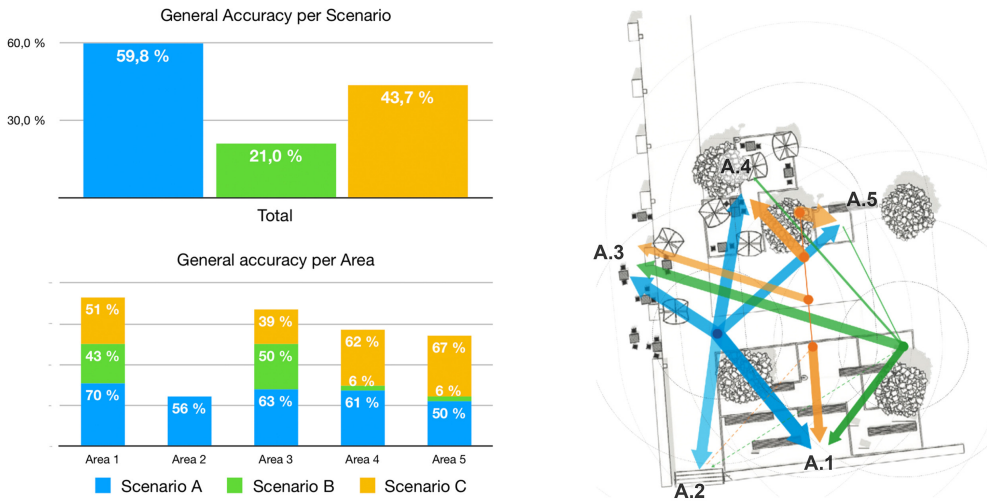
Concerning the three scenarios of degrees of freedom, the results showed differences in the performance of users in depicting the AR intervention, based on the analyses of screenshots, both the plan views and cross sections drawn by the participants after using the AR experiment, and the questionnaire. The analysis of screenshots showed a high relevance of the position and distance between the viewer and the observed areas, but more important was the quality of the visual field in terms of a clear view.





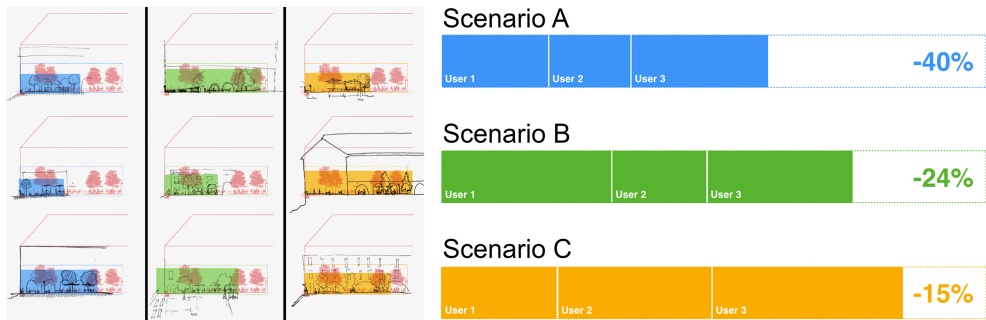
**Fig. 5:** Plan view analysis. Base sheet of paper with referential lines (left), user's sketch after the AR experience (middle), analysis through overlay technic (right picture) of the real condition (color elements) versus the user's sketch (black lines)

The plan view drawings were compared with the real plan view of the AR intervention, in terms of location, shape and quantity accuracy to quantify the overall distortion in each scenario. Results showed that distance and visual field were also relevant factors, but more important was the degree of freedom in each scenario, and the use of landmarks that acted as referential points when drawing.



**Fig. 6:** Through a rating method depending on the location, shape and quantity accuracy of the drawings compared with the real plan view, the graphic information was translated into quantitative. Arrow thickness indicates high/low overall accuracy in the analysis of the plan view drawings.

In the cross sections analysis, the distortion of the drawings was related to the position of the viewer within the intervention, but also to the body cues (position-movement sensation) they were able to collect when exploring through the AR scenario. When users were provided with more degrees of freedom in translation, more than in rotation, the drawings showed a higher accuracy.



**Fig.7:** Analysis of the cross sections showed a higher accuracy in the scenario where users were able to walk through the scene, showing the relevance of body cues during translation

Regarding the questionnaire, users recognized common uses and potential activities by their experience of the AR intervention. In terms of user's perception of the technology itself, results of the questionnaire analysis showed positive attitudes towards the use of mobile devices because of easy portability and light weight, as well as the easy use of the application. Negative critiques related to the software performance arose while tracking and deploying the augmentation, because of outdoor conditions as well as technical issues such as variations in light contrast, shadows and objects occlusion, among others.

## 6 Discussion

The results of the practical exercise applied during this research were compared with two other experiences related to the use of AR, whose results and premises proved to be interesting and constructive to analyze. The premises extracted from these two studies, first related to the primary reliance on landmarks within an environment over other sources of information like paths or body cues, when users had to take decisions during navigation (FOO et al. 2005). The second research, however, demonstrated that body cues, and specifically those related to translation more than to rotational movements, are necessary for the creation of accurate cognitive maps when compared with different scenarios with reduced body-based information feedback (RUDDLE et al. 2011). These two premises, landmarks and body cues are not contradictory but complementary within the performance of users in navigation and construction of mental maps of space. Body cues, through the estimation of the position of our body in space, contribute to path integration and the creation of cognitive maps (FOO et al. 2005). Information is gathered through internal senses that measure our acceleration, speed or angular rotation, but also through visual information such as optic flow (SRINIVASAN et al. 1997, as quoted by FOO et al. 2005).

These variables appeared with different intensity during the research analysis, specifically when studying the plan views and the elevation drawings. Both activities were intended to measure spatial visualization of the AR intervention through roughly similar exercises of hand drawings, but containing a fundamental difference aimed to explore these premises. In the plan views, users had referential lines with the location of a historical building and of a

border wall, references absent in the elevations activity. The results showed that in the plan views, the two areas drawn with the highest and more regular accuracy by users were those located next to these two existing elements, the old building and the border wall. The other areas presented less and more irregular accuracy between the users of the different scenarios. In the case of the elevations, given that there were no referential lines, users that had more degrees of freedom for translation had the most accurate drawings and better estimations of space regarding the horizontal extension of the AR model when compared with the other two scenarios of vision-based approach. The results coincided with the premises of the two mentioned studies, providing a high relevance to landmarks and body cues for the construction of more accurate cognitive maps.

## 7 Conclusions

One of the principal goals of this study was the determination of the key concepts within spatial cognition that are affected by the use of handheld AR. Throughout this research, it has been found that the use of handheld AR for the visualization of a landscape architecture design has an impact on the spatial cognition of users in several ways, among which this study considered aspects related to user displacement, spatial perception, and interpretation. These aspects represent a vast area within the spatial experience of users, affecting at different levels distinct subprocesses of spatial cognition. Specifically, through the theoretical and practical study of AR and the experiment performed, it has been concluded that in the context of landscape architecture, handheld AR affects spatial cognition in three different ways: firstly, by providing meaning to space, allowing people to understand and see new possible uses through 3D visualizations. Secondly, by enabling movement of the viewer and fostering exploration, which allows the integration of body cues when having a spatial experience. And thirdly, by affecting user's spatial visualization and spatial understanding of objects and their relations distributed on space, therefore altering their spatial cognition process.

Through the application of the practical exercise to analyze and compare the impacts on the spatial cognition of users, results showed that self-awareness and orientation of users were more required when more degrees of freedom were allowed, but in a minor extent when the movement possibilities were reduced. The process of spatial perception whereby information is gathered was partially affected by technical problems of the technology when tracking and placing the model within the real space. These issues provoke misleading positions of the AR content, regularly shacking and flickering within the device's screen. These technical flaws represented some software and hardware weaknesses that still do not find a definitive solution to its use for outdoor interventions. Despite the existence of these technical deficiencies, they did not represent an impediment to the understanding of the spatial relations within the AR exercise.

Diverse degrees of freedom for the exploration of the AR intervention were provided in all the scenarios proposed. The possibility to move while observing the augmented space was recognized as a positive aspect of AR, but considering rotation and translation as two different types of movement, rotation was the most demanded by users as a necessary and valuable attribute. This preference to rotational movements is due to the panoramic views that it allows, providing a seeming better awareness and understanding of the observer's position in space. This asseveration is supported by the performance of the different scenarios of vision-

based approach, wherein the one with the 360° of freedom reached the highest global accuracy in location, shape, and quantity when drawing a plan view of the AR intervention. A dichotomy appeared when the same scenario achieved the lowest accuracy in the cross section drawing, emphasizing the relevance that body cues have during translational movements more than in rotational ones, leading to a better estimation of distances when walking through the AR space. As a result, it is concluded that more degrees of freedom were not necessarily the main factor that produced the best results in terms of spatial understanding, but also the position of the viewer in relation to the intervention and the existence of real objects that acted as landmarks and reference points for the observers. Due to the complexity of factors involved in the results, and the small size of the study group, still the determination of which variable(s) is (are) more relevant than the other(s) demands future research in this field, in a theoretical but also empirical way with a larger sample size and a control group with traditional media such as plans and 2D visualizations.

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