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Navigation Tasks in Desktop VR Environments to Improve the Spatial Orientation Skill of Building Engineers

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Abstract: Virtual reality is a powerful tool for teaching 3D digital technologies in building engineering, as it facilitates the spatial perception of three-dimensional space. Spatial orientation skill is necessary for understanding 3D space. With VR, users navigate through virtually designed buildings and must be constantly aware of their position relative to other elements of the environment (orientation during navigation). In the present study, 25 building engineering students performed navigation tasks in a desktop-VR environment workshop. Performance of students using the desktop-VR was compared to a previous workshop in which navigation tasks were carried out using head-mounted displays. The Perspective Taking/Spatial Orientation Test measured spatial orientation skill. A questionnaire on user experience in the virtual environment was also administered. The gain in spatial orientation skill was 12.62%, similar to that obtained with head-mounted displays (14.23%). The desktop VR environment is an alternative to the HMD-VR environment for planning strategies to improve spatial orientation. Results from the user-experience questionnaire showed that the desktop VR environment strategy was well perceived by students in terms of interaction, 3D visualization, navigation, and sense of presence. Unlike in the HDM VR environment, student in the desktop VR environment did not report feelings of fatigue or dizziness.

Keywords: spatial orientation skill; virtual reality (VR); desktop VR environments; head mounted displays (HMD) VR environments; navigation; building engineering training; user VR experience; COVID-19

Citation: Carbonell-Carrera, C.; Saorin, J.L.; Jaeger, A.J. Navigation Tasks in Desktop VR Environments to Improve the Spatial Orientation Skill of Building Engineers. *Buildings* **2021**, *11*, 492. https://doi.org/10.3390/buildings11100492

Academic Editor: Svetlana J. Olbina

Received: 12 July 2021
Accepted: 17 October 2021
Published: 19 October 2021

1. Introduction

The use of 3D modeling tools combined with visualization techniques in virtual reality (VR) environments is already part of the building engineering design process. In 3D virtual building design, VR allows users to simulate the impact of a project on a geographical environment that is already built. VR facilitates the superposition of different structures and installations in projects and allows working with the constructional and architectural design elements of different buildings. Together, this allows for an understanding of the impact on the environment while virtually navigating around the 3D representation of the project [1]. Once inside the building, virtual reality also helps to create a three-dimensional space where objects, textures, materials, lighting and other 3D components can be displayed with a high level of reality. Virtual reality 3D graphic representation helps users to understand three-dimensional space, which facilitates decision-making around a project, compared to representations in two-dimensional plans and models [2]. It is 3D technology that generates evolutions that affect all stages of design, production and construction, and is being applied in building engineering to allow interactions between external and internal virtual environments with a high level of realism [1,3].

In a recent literature review, Strand [4] examined the use of VR in the domain of building engineering as part of the design process in international research during the last five years. Her review highlighted, among other aspects, the benefits of VR for a better "understanding of complex issues concerning design tasks, size and dimensions".

The use of virtual reality is attracting the interest of building engineering academic institutions. Virtual reality facilitates the creation of interactive virtual environments (IVEs) for professional training and architecture education, urban and landscape planning, and interior design. Recent research highlighted that VR has become an integral part of design studios in building engineering [5]. Authors such as Brandão et al. [1] affirm that "the insertion of contents that support the student formation related to new technologies is an important step towards the qualification of future architects to new design tendencies". These authors highlight VR as a powerful tool for teaching building engineering and urban planning by integrating the design, manufacture and assembly of buildings around 3D digital technologies, facilitating a spatial perception of three-dimensional space.

Regarding the spatial perception of three-dimensional space, when virtually designing a space, whether interior or exterior, the designer engages in a cognitive process of interpreting 3D space involving spatial skills, where spatial skill refers to, "the ability to generate, retain, retrieve, and transform well-structured visual images" [6]. Building engineers and landscape designers make use of spatial skills when designing spaces. Recent research highlights the importance of implementing learning strategies based on the development of spatial skills in the building engineering field. Planned acquisition of spatial skills at the beginning of undergraduate studies in building engineering will allow the development of more complex skills to solve complex problems in the real world [7]. Professional architecture organizations need higher education institutions to develop new methodologies in their curricula that promote the training of students based on the acquisition of spatial skills, which are listed as competencies to be acquired in the STEM degrees of building engineering, landscape planning and engineering [8–12].

One of the main components of spatial skills is spatial orientation, which refers to the knowledge of one's position and orientation within an environment [13–15]. The present research is focused on applying the use of specific strategies to develop spatial orientation skill via using VR building engineering environments. In building engineering, spatial orientation skill is necessary in both interior and exterior environments. In open, outdoor environments, building engineers need to position the project and themselves in a specific geographic location. In closed spaces (inside buildings), it is necessary to have knowledge of one's own position within the layout of the building.

In the field of building engineering and spatial skills research, one of the main areas in need of further development is understanding and examining the effectiveness of VR environments for supporting spatial skills training and improvement [16,17]. Using VR, building engineers can take a virtual tour of a certain environment, and navigate through the building, during which they need to be constantly aware of their position in relation to the other elements of the environment (orientation while navigation).

With the rise of VR technologies, navigation tasks are among the most common tasks in the design and project phases of a building. Thus, navigation in a virtual environment and its impact on the user's spatial orientation skill arouse great interest among researchers in the field of building engineering and other engineering disciplines (e.g., landscape planning and design) [8]. It is necessary to develop specific strategies for the development of spatial orientation skill in virtual environments and verify their effectiveness for improvement in building engineering higher education. In this regard, recent research has demonstrated the effectiveness of VR using head-mounted displays (HMD-VR) for navigation tasks in building engineering environments to develop spatial orientation skill [17].

However, the COVID-19 pandemic has led to a change in teaching strategies and technologies [2,5]. Specifically, in the field of virtual reality, the use of VR immersive techniques such as head-mounted displays (HMD-VR) in teaching tasks is limited by the possibility of contagion, and VR desktop environments can be used as a viable alternative. It is therefore necessary to examine whether VR desktop environments have the same effectiveness as the head-mounted displays (HMD-VR) for the development of spatial orientation skill in building engineering higher education.

This present research discusses the results of a workshop carried out with a VR desktop environment for the development of spatial orientation skill. In this workshop, 25 building engineering students performed navigation tasks in a desktop VR building environment. These results were compared to a previous building workshop in which navigation tasks were carried out using head-mounted VR displays [17]. By checking the effectiveness of other VR environments, such as VR desktop environments, teaching strategies can be validated with this technology for the development of spatial orientation skill.

Therefore, the research hypotheses were as follows:

Hypothesis 1 (H1). *Specific strategies with navigation tasks using desktop VR environments generate a significant gain in spatial orientation skill.*

Hypothesis 2 (H2). *The gains in terms of spatial orientation skill with desktop VR environments are similar to those obtained with HMD-VR environments.*

2. Spatial Orientation Skill in the Context of Virtual Environments (VE)

In building engineering settings, spatial orientation plays an important role in interpreting complex architectural spaces and identifying with places [18]. There are numerous definitions of spatial orientation, a sub-component of spatial skills, including "the ability to remain oriented in a spatial environment when the objects in this environment are observed from different positions" [19]; "the three-dimensional orientation in space during movement" or "the ability to orient oneself towards the environment and to be aware of one's position in space" [20]; and "the ability to physically or mentally orientate in space [21]".

Spatial skills, and therefore spatial orientation, can be developed with specific training using the appropriate tools [22–28]. At the University of La Laguna, workshops with technologies such as geoportals, game engines, augmented reality and 3D CAD apps have been used to develop the spatial orientation skill of engineering students [8]. Among these technologies, geoportals and augmented reality have shown the greatest effectiveness in improving spatial orientation skill. In these workshops, different forms of relief were used to carry out spatial orientation tasks such as determining locations and routes. The gains obtained in spatial orientation skill with workshops based on these technologies have been measured with the same tool used in the present research, allowing for direct comparisons to be made.

In the field of building engineering, virtual reality is a 3D tool that is increasingly used in teaching toward higher degrees, as well as in professional studios. VR greatly facilitates the visualization of proposals for a building engineering project and allows the participation of different stakeholders in the project for better decision-making. Thus, the implementation of teaching strategies based on virtual reality is increasingly necessary, as it will help in training future building engineers on new design trends [1]. In the teaching field, VR-based teaching strategies make up so-called virtual learning environments (VLEs). A VLE allows the virtual construction of a building, without the limitations of the physical world, which offers great possibilities for students and teachers. Previous research in spatial skills training through VR has demonstrated that VR-based activities are equivalent to similar activities done in the real world [29,30].

Therefore, it is necessary to determine the potential of VLEs for the development of spatial orientation skill, for which it is necessary to establish which tasks are involved in orientation processes in space. Two main activities are related to the acquisition of spatial orientation skill: an aerial or map-like perspective (map learning or survey learning) and a ground-level perspective (route-based learning, navigation, or wayfinding) [13,31]. In map learning, while using a map (traditional 2D or 3D map), a spatial reference system is used in which one´s situation is defined by the orientation towards north, which is what appears on the map. On the other hand, in route-based learning, navigation or wayfinding, there is no determined north for the spatial environment, and the orientation is acquired through successive views where movement causes the point of view to change continuously [32–34]. It is the type of orientation that we acquire, for example, when walking through the streets of a city, and we orient ourselves through successive views while changing our points of view. It is what some researchers call route knowledge [35,36].

Of the two activities related to the acquisition of spatial orientation skill, this research is focused on navigation tasks in virtual environments. In virtual reality, users can experience the visual effect space by adjusting their perspective and movement (navigation) in the virtual environment. In the field of virtual reality, it is not only important that the design, but also those individuals can freely navigate through the designed space [37,38]. Authors such as Santos et al. [39] affirm that navigation is one of the core tasks in virtual environments. In building engineering, it is common to take tours of the VR environment to visualize a building or its interior from different orientations, in which the building engineer has a great sense of presence and immersion. Although these terms may seem synonymous, they are not. Immersion is associated with technologies that increase one´s sense of presence [40,41], and the immersion effect generated by VR systems can cause disorientation problems. The sense of presence is a characteristic of virtual reality technology. Presence is defined as the feeling of belonging in the VR world, or, in other words, it is related to how much the user feels that the VR is real [2,42]. This sense of presence generates in the user a feeling of immersion ("perception of being involved, included and interacting with an environment that provides a continuous flow of stimuli and experiences" [43]). Different virtual reality technologies generate different levels of immersion, depending on the level of realism and how the user interacts with the system. In this way, the so-called high immersive VR environments and low immersive desktop VR environments emerged. There are also classifications that include another category: semi-immersive, which is similar to low-immersive systems but uses high-resolution projections or larger screens [4], although semi-immersive systems are not considered in the present research.

High-immersive VR systems use HMDs, which completely fill the user's field of view. Auditory and tactile sensory aspects can be added to the environment allowing the user to interact with the system using a joystick, hand-held sensors, gloves, or a bodysuit. Low-immersive desktop VR systems use a conventional computer with a monitor, keyboard and mouse, which the user operates to interact with the environment represented on the screen (Figure 1, left). Users can perceive high-immersive environments as part of their body. That is, users see the environment by moving their body or turning their head, as they would in a real environment (Figure 1, right). In contrast, a low-immersive system is separate from the users' body [4,44,45].

Figure 1. Low-immersive desktop environment (**left**) and high-immersive HMD-VR environment (**right**). Adapted from [45–47].

However, these virtual reality environments can present difficulties for users when it comes to orienting themselves. Although numerous researchers have highlighted the potential of VR for developing spatial skills [48–50], Nguyen-Vo, Riecke and Stuerzlinger [51] noted that, "Despite recent advances in virtual reality, locomotion in a virtual environment is still restricted because of spatial disorientation". Chang, Kim and Yoo [52] also noted that disorientation problems can arise while navigating in a virtual environment. In recent research carried out with VR in building engineering environments, no significant differences were found in terms of increases in spatial orientation skill [7]. Therefore, it is necessary to study the effects of specific strategies for the development of spatial orientation skill through navigation activities in VR environments and check whether there are significant differences between low and high immersive environments when applying these strategies. This is the question raised in the present research, in which a specific strategy for developing spatial orientation skill in a desktop VR environment is presented, and quantitative data are obtained regarding the impact of this strategy on spatial orientation.

3. Materials and Methods

In this research, a workshop was conducted in a low-immersive desktop environment: the VR environment was built and designed by the Building Engineering Faculty of the University of La Laguna, in the city of La Laguna, Canary Islands, Spain. Participants interacted with a VR environment created with the Unity 3D Game Engine free student license (www.unity3d.com, accessed on 6 June 2021). The tool used to measure the impact of the workshop on participants' spatial orientation skill was the Perspective-Taking/Spatial Orientation Test [53,54]. In addition, a questionnaire on user experience with the virtual environment using a 10-point Likert Scale was administered.

3.1. Software

With the Unity 3D Game Engine free student license, building engineering environments can be graphically represented in real time. The application's powerful rendering engines offer a first-person perspective that strengthens the sense of presence and immersion. The user takes an interactive tour of the VR environment through a first-person shooter (FPS) controller, which allows them to make movements (forward, backward, left, right, up, down). A great advantage of Unity 3D is that it is multiplatform software; that is; it works on Windows, Linux, and Mac operating systems. This facilitates more flexible implementation in educational settings, as there are no operating system limitations, making the program accessible and easily downloadable for all students. In the workshop carried out, the participants used their own computers, following the "bring your own device" BYOD trend of the Higher Education New Media Consortium Horizon Report [55]. If a student did not have a computer, the instructor provided one. To conduct the workshop, participants only needed a web browser to navigate in the VR environment.

3.2. Perspective-Taking/Spatial Orientation Test

The Perspective Taking/Spatial Orientation Test [53,54] used in the present research is a paper-and-pencil test used to measure spatial orientation skill. It is correlated with navigation performance and has been widely used in numerous studies in the field of spatial skills [8,17,56–60]. A new computerized version of the test has been developed; the test and the associated task instructions are available on the Open Science Framework [61].

The test consists of 12 items. Scores on this test are computed as the error (in degrees) between the direction marked by the user and the correct direction. Therefore, lower scores on this measure indicate less error and thus, better perspective taking.

Test Instructions

There are 12 items in this test, one on each page. On each item, the participant will see a series of objects and an "arrow circle" with a question about the direction between some of the objects. The participant must imagine that they are standing at one object in the array (which will be named in the center of the circle) and facing another object, named at the top of the circle. The task is to draw an arrow from the center object showing the direction to a third object from this facing orientation (see example in Figure 2).

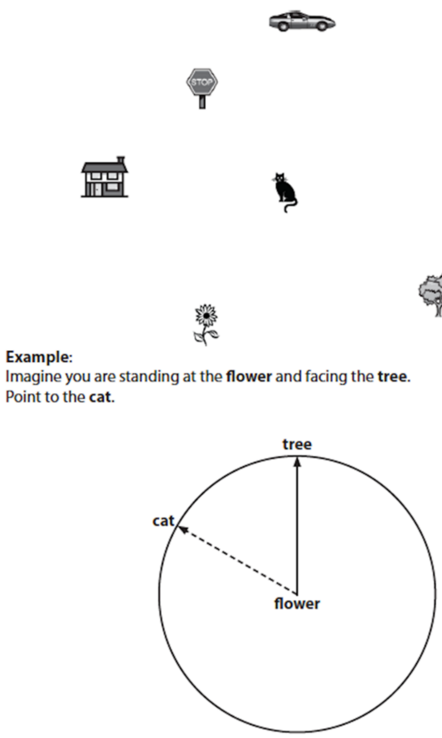

Figure 2. Perspective Taking/Spatial Orientation Test item example.

For each item, the array of objects is shown at the top of the page and the arrow circle is shown at the bottom. The participant must not make any marks at the top of the page or turn or rotate the test booklet. The correct directions should be marked in the specified time to perform the test, if possible, which is five minutes. The participant should not pick up or turn the test booklet until instructed to do so by the instructor. Before starting, the participant can ask the instructor if he or she has any questions about what do. The time to perform the test is 5 min.

The first item of the text is an example (Figure 2).

In the example, the proposed perspective is: "Imagine you are standing at the flower and facing the tree. Point to the cat". That is, the user is located by the flower, and is asked to look straight ahead at the tree and point out where the cat would be. In this position, the cat would be on the left, according to the arrangement shown in the upper part of the figure. In the lower part of the figure, the dashed line marks the correct direction the cat would be from the proposed perspective, which is what the user should draw.

3.3. Questionnaire

In the present research, an adapted version of the Questionnaire on User eXperience in Immersive Virtual Environments (QUXiVE) was used to measure user experience. It is a standardized questionnaire validated by Tcha-Tokey et al. [62,63]. The definition of user experience (UX) according to the ISO 9241-210 standard is "The user's perceptions and responses resulting from the use of a system or a service". The full form of the QUXiVE is comprised of 82 items with subscales assessing variables such as presence, engagement, immersion, flow, emotion, usability, technology adoption, judgment, and experience consequence. The authors of this questionnaire indicate that it is not necessary to use the version, and that rather, subsets of items can be selected to measure specific variables of interest.

A recent study in the field of Serious Games Applied in Architectural and Urban Design Education [2] used a survey of 10 questions on usability and user experience to provide information about the product, experience and technology used. This survey analyzed aspects such as the user's perception of the VR system and its capacity to design the urban/architectural space; the personal perceptions about the user's motivation in the use of VR systems and, finally, about personal motivations and perceptions of usefulness and further training. We took this 10-item model as a starting point, and selected items from the standardized QUXiVE questionnaire related to the activities carried out in the workshop. Thus, in addition to including items related to product, experience and technology such as those in the aforementioned survey, we included items focused on orientation, the feeling of immersion and possible adverse aspects of this technology such as fatigue and dizziness.

Each item was scored on a 1–10 Likert scale (1 = strongly disagree, 10 = strongly agree), which is the Likert scale of the QUXiVE test questionnaire. The items selected for use in the present study were those related to the navigating experience offered to the participants (the sense of presence, the 3D visualization, engagement, and overall experience). These aspects allowed us to compare with other workshops that used other technologies or different strategies to improve spatial orientation skill.

After completing the workshop, the students responded to the 10-item questionnaire about their experience with the virtual environment (Table 1). To check its reliability, Cronbach's alpha was calculated.

Table 1. Workshop questionnaire.

Workshop Questionnaire
1. "My interactions with the virtual environment seemed natural"
2. "I could examine objects from multiple viewpoints"
3. "The visual aspects of the virtual environment involved me"
4. "The sense of moving around inside the virtual environment was compelling"
5. "Personally, I would say the virtual environment is practical"
6. "Personally, I would say the virtual environment is manageable"
7. "I found this virtual environment amateurish (1)/professional (10)"
8. "I suffered from fatigue during my interaction with the virtual environment"
9. "I suffered from dizziness during my interaction with the virtual environment"
10. "During the workshop, when carrying out the navigation tasks in the virtual environment, I sometimes lost my orientation."

3.4. Methodology: The Workshop

The workshop was a teaching activity included in the study plan of activities to be carried out for the Degree in building engineering at the University of La Laguna.

The VR environment was created from a 3D model made with the Autodesk Revit Building Information Modeling (BIM) application (free educational license) (Figure 3). This model was imported into Unity 3D, to create the VR environment, in which a FPS controller was inserted in order to interact with the model.

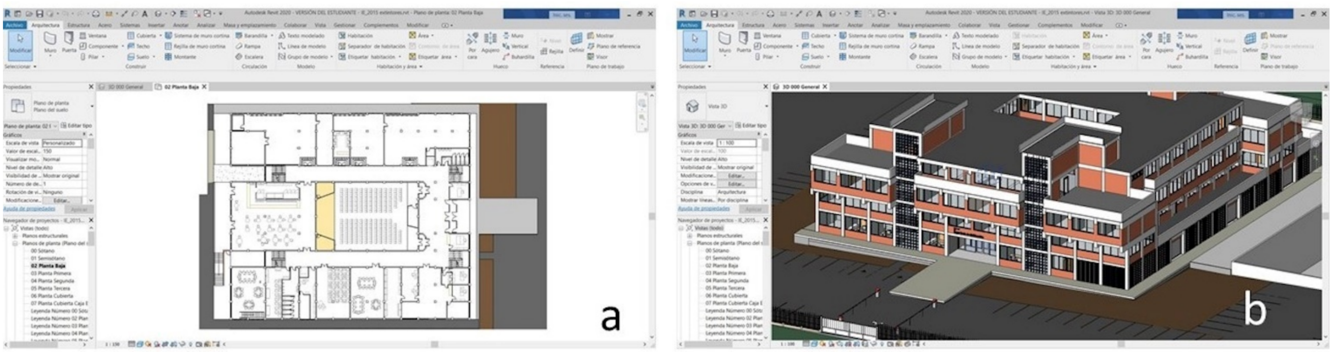

Figure 3. (**a**) 2D and (**b**) 3D model of Building Engineering Faculty of the University of La Laguna, created with Autodesk Revit by the authors.

The objective was not to make a 3D model of a realistic building, but rather an operational 3D model that, taking the architectural design as a starting point, would allow us to explore its interior and do orientation exercises/tasks. With the onset of the COVID-19 pandemic, the use of virtual reality glasses was ruled out and the model was finally implemented in a desktop VR environment in which the participants interact with the model using keyboard and mouse (FPS controller).

3.4.1. Participants

Twenty-five second year building engineering students of the University of La Laguna participated in the workshop, 17 men and 8 women. The mean age of the participants was 20.76 years, with a standard deviation (s.d.) of 1.51. The Department of Techniques and Projects in Architecture and Engineering at the University of La Laguna carries out continuous research in the field of spatial skills of building engineering and engineering students. For this reason, at the beginning of each academic year, students perform the Perspective Taking Spatial Orientation Test, regardless of whether they participate in a workshop or not. Specifically, on this occasion, the students completed the pretest 20 days before participating in the workshop. The results of the present workshop were compared with those of another workshop carried out previously with HMDs, in which 32 other students participated, 19 men and 13 women, with a mean age of 20.50 years (s.d. = 1.85) [17]. In both workshops, participants were asked if they had any previous experience with immersive 3D environments, and none had contact with these technologies. None of the participants had performed the Perspective Taking Spatial Orientation Test before.

Regarding control group, recent research has been carried out at the same University in the field of spatial orientation skill [64,65], in which workshops were performed with the same cohort of students (second-year building engineering and engineering students), also using the Perspective-Taking Spatial Orientation Test. In these previous workshops [64,65], the students who did not participate in the workshops (control groups, n = 35 and 60 respectively) did not obtain a significant gain in their spatial orientation skill (p-level = 0.113 and 0.202, respectively). That is, there was no improvement in orientation if specific training was not performed. For this reason, and also due to the reduced number of students because of the pandemic, a control group was not considered in the present research.

3.4.2. Procedure

Previous research in the field of spatial orientation has been carried out based on the main activities related to the acquisition of spatial orientation skill mentioned in point 2: map learning or survey learning and route-based learning, navigation or wayfinding [13,31]. Geoportals have been used with map learning activities, and augmented reality technology has been used with navigation activities [8].

In the present research, a navigation strategy workshop was carried out using VR technology (Table 2).

Table 2. Strategies for the development of spatial orientation.

Strategies for Spatial Orientation Skill Development	
Map Learning or Survey Learning	**Route-Based Learning, Wayfinding or Navigation**
Previous research Geoportals	Previous research Augmented and Virtual Reality Preset research Desktop Virtual Reality

The workshop performed involves tasks that require students to complete a series of virtual navigation tasks to support the development of their spatial skills. This kind of activity is standard in the spatial navigation training literature [16,66–69]. These types of tasks align with the kinds of activities students and engineers would participate in during real design and development projects. When designing a building using virtual reality it is necessary to maintain orientation when navigating the virtual 3D environment [21]. With virtual reality, users can experience the visual effect space by adjusting their perspective and movement (navigation) in the virtual environment. While navigating, orientation is obtained through successive views obtained from a constantly moving point of view [32–34].

The navigation strategy carried out in the present research was based on previous research in which a virtual building walkthrough was used in a desktop virtual environment. In these previous works, internal and external activities were performed [1,51]; and navigation tasks such as forward and backward motion, navigation to a specific point and navigation through doorways were carried out [2,16,39], which are the movements we worked with in this workshop. These authors highlighted the usefulness of the VR desktop environments from the point of view of global user performance. In turn, Santos et al. [39] pointed out the need to study the impact of orientation tasks in virtual environments, which we deal with in the present research.

The workshop was structured in four phases (Table 3):

Table 3. Workshop structure.

Phase 1: Instruction				*Timing*
• Description of 3D model creation with Revit and Unity 3D • Basic training as how to operate with the FPS to move around and interact with the 3D environment				2 h
Phase 2: Navigation Tasks				2 h
Navigation task	Navigation task from	Target location	VR-Interaction movements	
1	Outside the building	Outside the building	Forward/backward Left/right	
2	Inside the building	Inside the building	Forward/backward Left/right Jump (overcome obstacles)	
3	Inside the building	Inside the building	Forward/backward Left/right Jump (overcome obstacles)	
4	Inside the building	Inside the building	Forward/backward Left/right Jump (overcome obstacles)	
5	Inside the building	Inside and outside the building	Forward/backward Left/right Jump (overcome obstacles and up/down stairs) 360° display movements with the mouse	
6	Inside the building	Inside the building	Forward/backward Left/right Jump (up/down stairs)	
Phase 3: Perspective Taking Spatial Orientation Post-test Pre-test was performed before the workshop				5 min
Phase 4: User questionnaire 10 items on a 1–10 Likert Scale				20 min

Phase 1: Instruction; 2 h. The students were informed about the process of creating the 3D model with Revit and Unity 3D and received basic training on how to use the FPS controller to move around and interact with the 3D environment. The term interaction, in the VR field, is understood as the ability of users to interact with virtual things and objects around them as if they were in a real environment. The operation of the FPS controller in the workshop was through the keyboard and mouse. The A key was used to go to the left,

D to the right, W to go forward and S to go back. The space bar allowed the user to jump, which allowed them to climb the uneven steps when traveling up stairs and to overcome obstacles. By using the mouse, it was possible to move the visualization left/right and up/down in order to have a 360° image of the virtual environment.

Phase 2: Navigation Tasks; 2 h. Once inside the architectural VR environment, students have to perform 6 navigation tasks, in which different locations (targets) were proposed within the building. To achieve these objectives, they had to follow different proposed routes and visualize certain details of the virtual environment, which allowed the instructors to verify whether the participant reached the proposed locations. VR technology allows the inclusion of auxiliary orientation elements such as maps or orthorectified views of the research area, other than only a first-person view. In the present research, our intention was to measure the effect of VR on spatial orientation without the support of these accessory views.

- Navigation task 1 (Figure 4): Access the campus of the Building Engineering Faculty and stand in front of its façade. To the right of the façade, you will see a wall with glass blocks. How many glass blocks make up a row?

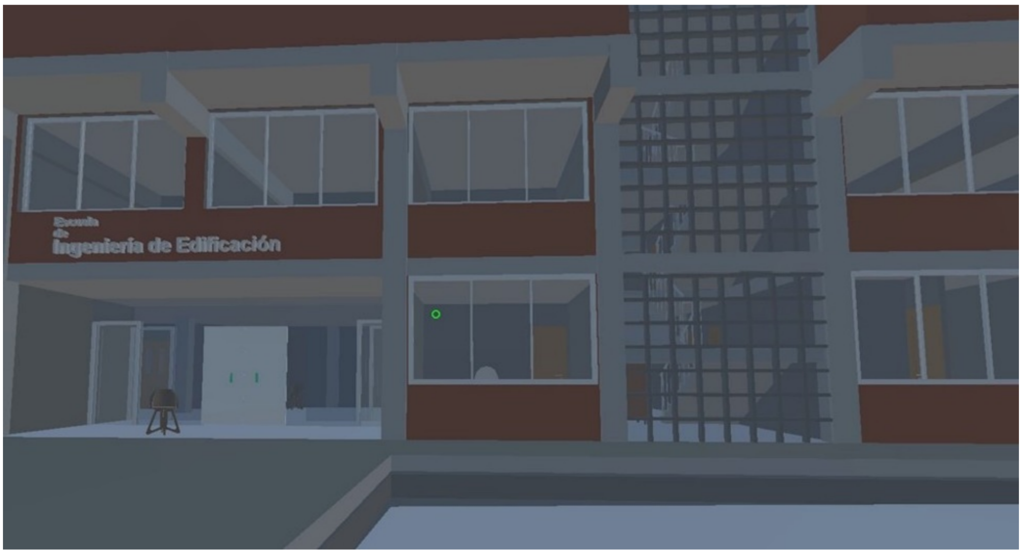

Figure 4. Navigation task 1: Building Engineering Faculty of the University of La Laguna desktop VR environment (façade).

- Navigation task 2 (Figure 5): Once you are inside the building, you will see two double doors in front of you on the left and right. Enter through the door on the right and you will be in the school auditorium. Walk to the stage and get on it (you will have to jump). Walk to the edge of the stage and visualize the entire auditorium from the back of the room to the hole near your feet (try not to fall off the stage!). You will see two areas with armchairs separated by a central corridor. From your position, look at the seating area to the left of the aisle. How many seats are in the second row?

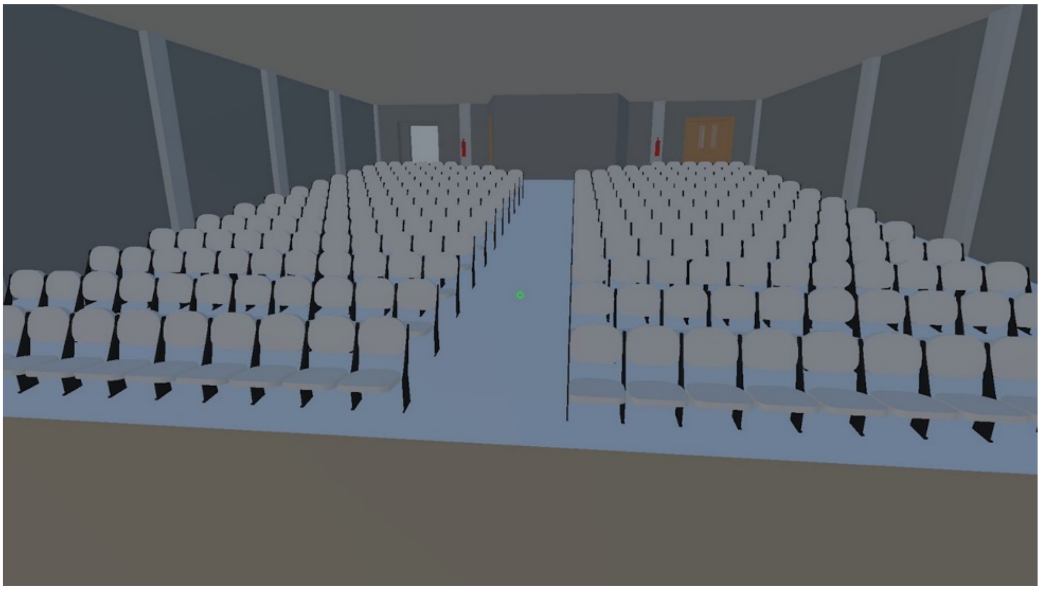

Figure 5. Navigation task 2: Building Engineering Faculty of the University of La Laguna desktop VR environment (school auditorium).

- Navigation task 3 (Figure 6): Exit the auditorium through the door on the left. Walk to your left, you will see an elevator. It cannot be used during the pandemic. What bad luck! You have to turn 180° and go toward the stairs. When you reach the stairs you will see, on your right, a vending machine. How many buttons are on the vending machine keypad?

Figure 6. Navigation task 3. Building Engineering Faculty of the University of La Laguna desktop VR environment (stairs/vending machine).

- Navigation task 4 (Figure 7): Turn left, then left again. You will see a long corridor. At the end of the corridor, on the left, there is a double door. Go through that door and you should be in the Student Center food court. Walk right to the bar counter and order a latte ("Order a latte" is a touch of humor to break up the numerous instructions; it is not a real task.). Through the back windows, on your left, you will see the exterior of the building. Get out and get some air and come back in again. Now, walk parallel to the bar counter and leave four tables behind. Turn around. From your position, how many lights are there on the ceiling of the Student Center food court?

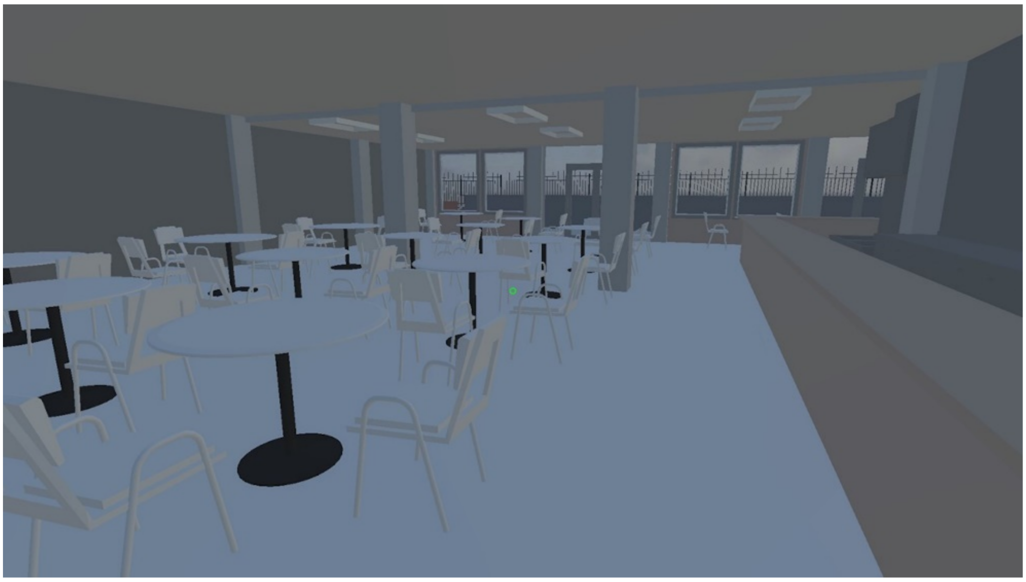

Figure 7. Navigation task 4. Building Engineering Faculty of the University of La Laguna desktop VR environment (Student Center food court).

- Navigation task 5 (Figure 8): Exit the Student Center food court through the door on the right. Walk to the left and you will see the stairs. Go up one floor, you are already in the corridor on floor 1. Walk down the corridor until you reach some windows that look towards an inner courtyard. Take a look at the inner courtyard from different points of view. How many windows face the inner courtyard? Is it possible to see the sky through the inner courtyard? Stand in front of the stairs to go up to the second floor. How many steps are in the first flight of stairs?

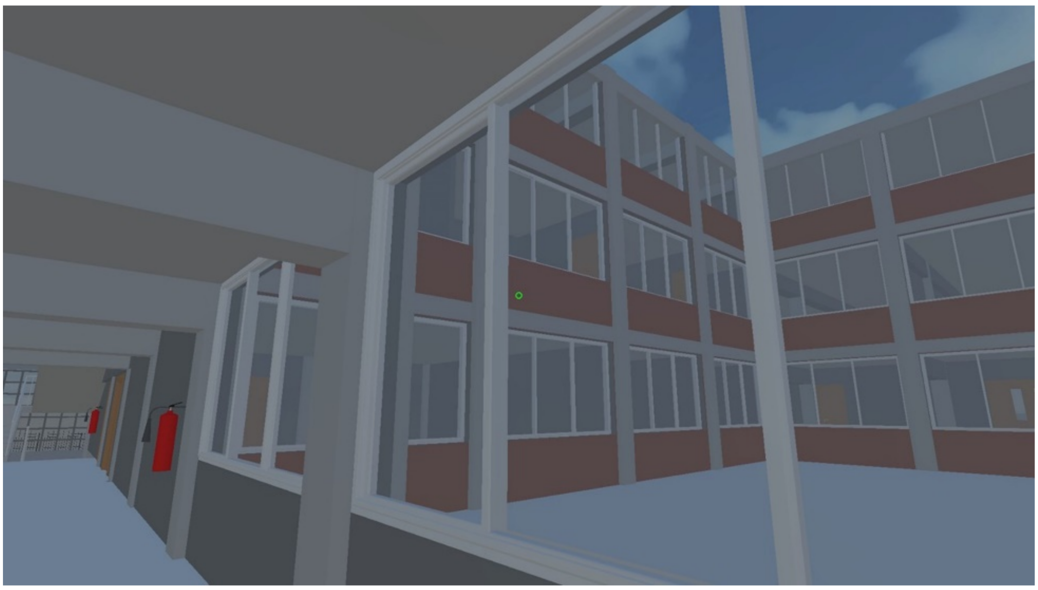

Figure 8. Navigation task 5. Building Engineering Faculty of the University of La Laguna desktop VR environment (floor 1 corridor and courtyard).

- Navigation task 6 (Figure 9): Go upstairs and you will reach the corridor on the second floor. On which wall are the fire extinguishers, on the right wall or the left wall? How many fire extinguishers are there in the corridor?

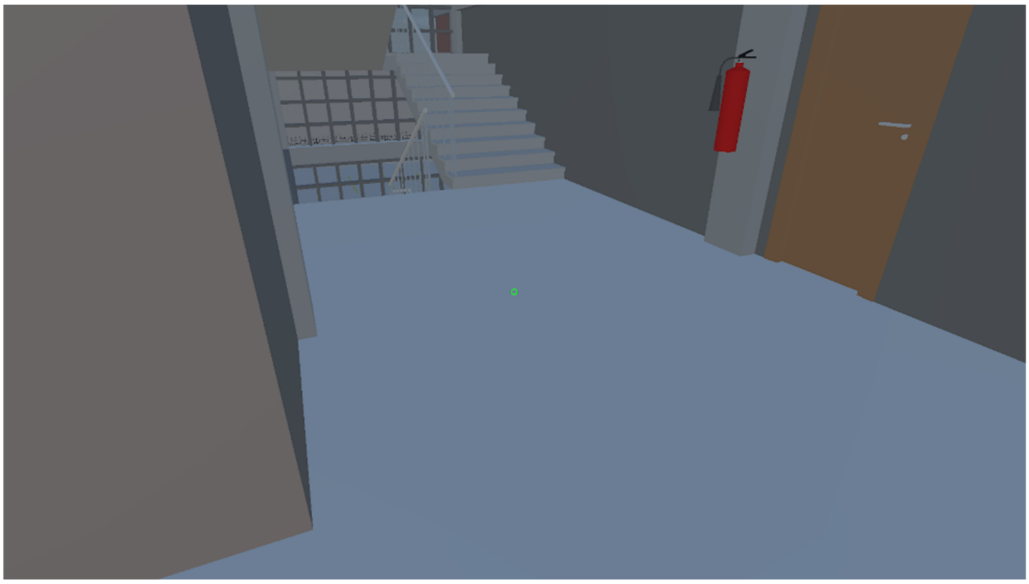

Figure 9. Navigation task 6. Building Engineering Faculty of the University of La Laguna desktop VR environment (floor 2/extinguishers).

Phase 3: Perspective Taking/Spatial Orientation Post-Test; 5 min. Upon completion of the six navigation tasks, the participants took the Perspective Taking Spatial Orientation (Post-Test). The authors of the Test instructions specified the 5-min time.
Phase 4: User questionnaire; 20 min. The students responded to a questionnaire on a 1–10 Likert scale about their experience in the desktop virtual environment.

4. Results

4.1. Spatial Orientation Skill

To address the first hypothesis that navigation tasks using a desktop VR environment would generate a significant gain in spatial orientation skill, a paired-samples t-test was conducted comparing perspective taking scores before and after completing the workshop. The results revealed that prior to the workshop, students had an average perspective taking error of 35.75° (SD = 20.67), and after completing the workshop their error decreased to an average of 24.39° (SD = 18.10). This decrease in error resulted in a significant paired-samples t-test with a medium effect size, t(24) 3.72, $p < 0.001$, d = 0.74. In other words, the significant gain in spatial orientation skill was 11.36°, or 12.62%.

In the HDM-VR workshop [17], the participants obtained a gain of 12.81° (14.23%) in spatial orientation skill. To address the second hypothesis that the desktop VR and HDM-VR environments would both result in significant gains in spatial orientation skill a two (VR environment: desktop vs. HMD) by two (timepoint: pre vs. post) repeated-measures analysis of variance (ANOVA) was conducted with the Perspective Taking score as the dependent variable. As shown in Figure 10, there was a significant main effect of time point, such that in both environments, students showed a significant decrease in perspective taking error from pre to post test, F(1, 55) = 38.74, $p < 0.001$, ηp2 = 0.41. There was no main effect of condition, F(1, 55) = 3.38, $p = 0.07$, ηp2 = 0.06, and importantly, the interaction between VR environment condition and time point was not significant, F(1, 55) = 0.14, ns, ηp2 = 0.003. Together, these results indicate that both the desktop VR and HDM-VR environments facilities significant gains in spatial orientation skill and that this improvement was equal across the two training formats.

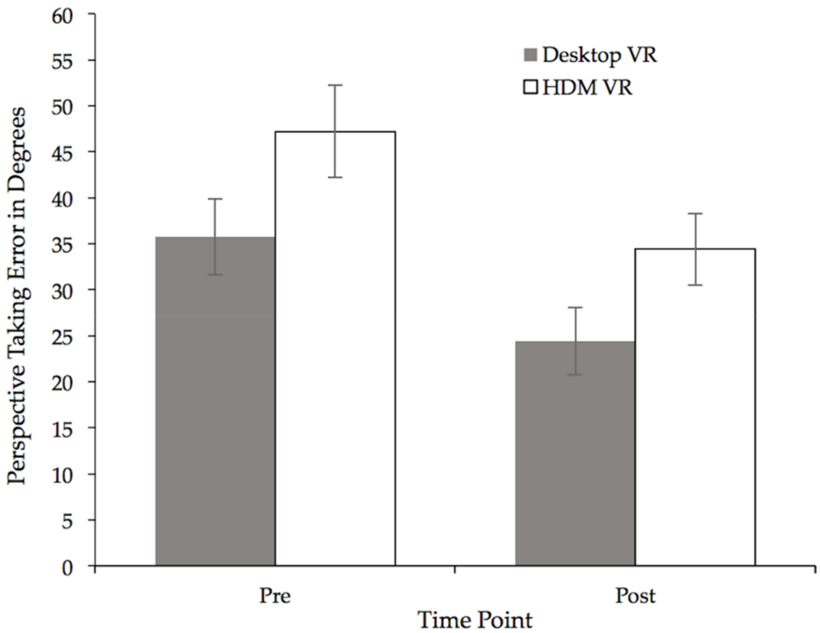

Figure 10. Mean perspective taking error as a function of time point and VR environment. Error bars represent standard error of the mean.

No gender differences were found in either of the two cases.

4.2. Questionnaire

The reliability of the questionnaire was verified with Cronbach's alpha. The value obtained in this research is 0.712. Cronbach's alpha values between 0.70 and 0.90 indicate good internal consistency [70]. Table 4 shows the results of the questionnaire.

Table 4. Workshop questionnaire results.

Workshop Questionnaire	
Item	**Mean Score (1–10) (*SD*)**
1. "My interactions with the virtual environment seemed natural"	6.84 (2.15)
2. "I could examine objects from multiple viewpoints"	8.76 (1.42)
3. "The visual aspects of the virtual environment involved me"	7.00 (1.76)
4. "The sense of moving around inside the virtual environment was compelling"	7.52 (1.48)
5. "Personally, I would say the virtual environment is practical"	8.28 (1.66)
6. "Personally, I would say the virtual environment is manageable"	8.00 (1.71)
7. "I found this virtual environment amateurish (1)/professional (10)"	5.40 (1.68)
8. "I suffered from fatigue during my interaction with the virtual environment"	2.00 (1.78)
9. "I suffered from dizziness during my interaction with the virtual environment"	1.32 (0.63)
10. "During the workshop, when carrying out the navigation tasks in the virtual environment, I sometimes lost my orientation."	5.88 (1.59)

5. Discussion

The outbreak of the COVID-19 pandemic has meant a change in the educational model in which traditional face-to-face teaching has migrated towards methods based on new technologies in online contexts. In this new scenario, educational institutions adapt their contents and subjects to a new environment in order to validate the students' competency. As part of this adaptation, new technologies and teaching methodologies in building engineering have to be identified [2]. In this context, authors such as Aydin and

Aktaş [5] highlight the great impact that the pandemic has had on building engineering studies and promote working with infrastructures for the teaching of building engineering based on virtual reality technologies. The use of VR is also affected by the pandemic in teaching environments, as teaching is carried out online or in adapted face-to-face scenarios with significant preventive security measures that restrict contact, in which the use of HMD is curtailed because of the risk of contagion. This means desktop VR environments have emerged as an alternative to HMDs, although their effectiveness in terms of the development of spatial orientation skill needs to be verified.

In this research, a workshop designed to train students in spatial orientation skill was carried out, in which students worked in a VR desktop environment with their own personal computers performing navigation tasks. Navigation tasks were used because in the design and construction of buildings, when working with virtual reality, navigation tasks are carried out within three-dimensional environments, in which it is necessary to be constantly oriented. In fact, the definition of spatial orientation as "three-dimensional orientation in space during movement" [21] is related to navigation tasks.

Therefore, it is necessary to check whether this strategy can achieve significant improvements in spatial orientation skill. It is also interesting to compare it with previous similar experiences in which VR technologies based on HMDs were used.

5.1. Research Hypotheses H1

H1: Specific strategies with navigation tasks using a desktop VR environment generate significant gain in spatial orientation skill.

The participants in the workshop obtained a significant gain of 11.36° in the Perspective Taking Spatial Orientation Test, which, translates to a gain of 12.62% in spatial orientation skill. The first hypothesis is confirmed; therefore the strategy based on navigation tasks using a desktop VR environments is effective for developing spatial orientation skill. No significant differences were found with respect to gender.

5.2. Research Hypotheses H2

The gain obtained in spatial orientation through navigation tasks in desktop and HMD VR environment were 11.36° (12.62%) and 12.81° (14.23%) respectively. There were no significant differences between the two environments in terms of gains in spatial orientation skill.

These gains were lower than those obtained in previous studies that also used the Perspective Taking Spatial Orientation Test [8]. In those studies augmented reality and geoportals were used, in which navigation and map-learning strategies were combined, with gains of 20.1° (22.33%) and 19.10° (21.22%) respectively. According to these results, VR environments have less power to improve spatial orientation in relation to other technologies. The problems associated with the disorientation generated by navigation in virtual environments detected by other studies [2,51,71,72] seem to be in line with the results obtained. On the other hand, with the technologies that resulted in the greatest gains (augmented reality and geoportals), combined navigation and map learning strategies were used. In this regard, recent research confirms that strategies based on navigation and map-learning tasks are more effective than strategies based exclusively on navigation tasks [8].

5.3. Discussion of Questionnaire Results

In items 1 to 6, the higher the score, the better the user's perception of the workshop. Average scores varied between 6.84 (minimum) and 8.76 (maximum), indicating that the students' perception was good.

Regarding item 1, they naturally interacted with the VR environment. Although with the mouse and keyboard the score for this item was high (M = 6.64, SD = 2.15), it was lower than the scores obtained for items 1 to 6. There is great interest in studying what factors can affect navigation in virtual environments, based on the different levels of interaction that HMDs and desktop VR environments can offer. In this sense, Santos et al. [39] in a comparison between HDM and desktop VR found a user preference for desktop VR in terms of interaction, but that research was carried out in 2008, when VR technology was not as developed as it is now. More recent research, on the other hand, indicates that HDM-VR devices together with navigation control tools can offer a greater interaction and sense of presence with the environment compared to desktop VR [73].

Participants found it easy to visualize objects from different points of view ($M = 8.76$, $SD = 1.42$; item 2). This was a predictable result, as the 3D VR environment allows for 360° views of any object. This characteristic is important in the present study, as it is related to one of the definitions of spatial orientation skill: "the ability to remain oriented in a spatial environment when the objects in this environment are observed from different positions" [19].

The students felt involved with the visual aspects of the environment ($M = 7.00$, $SD = 1.76$; item 3). This item is related to immersion ("perception of being involved, included and interacting with an environment that provides a continuous flow of stimuli and experiences") [43]. Factors related to realism can increase the sense of presence [74]. In this regard, more details (textures, colors...) and lighting effects that give the 3D model more realism could improve this score.

Item 4 is a (sense of moving) related to navigation. The score obtained for this item was high ($M = 7.52$, $SD = 1.48$). This indicates that the devices for navigating the virtual environment used in the workshop (mouse and keyboard), together with the monitor display, allowed participants to navigate comfortably. Comfortable and efficient movement between locations allows the user to move through the VR environment in a simple, fast and light way, which helps to focus the user's attention on tasks more important than mere navigation [39]. This item is related to item 6, in which also obtained high score ($M = 8.00$, $SD = 1.71$). Participants felt comfortable within the virtual environment (they found it "manageable") with the tools available to them (monitor, mouse and keyboard).

Students perceived the VR environment as practical, with a fairly high score ($M = 8.28$, $SD = 1.71$). Students perceived that this technology could have a direct effect on their studies and their profession. They considered it practical, that is, possible to use, and not just as educational content, which they sometimes do not consider so practical. After the workshop, the participants received training on real examples of the use of VR as a tool to facilitate decision-making for different stakeholders around a building engineering project, and they were able to see how practical it can be.

We were not surprised by the student´s opinion on item 7: "I found this virtual environment amateurish (1)/professional (10)". The result shows a mean of 5.4 ($SD = 1.68$). The created virtual environment created was a proof of concept whose objective was to develop spatial orientation skill; it was not focused on realism.

Items 8 and 9 informed us about possible unwanted effects of virtual reality: fatigue and dizziness. In both cases, the values obtained were low ($M = 2.00$, SD = 1.78 and $M = 1.32$, $SD = 0.63$ for items 8 and 9 respectively). Studies have reported fatigue and dizziness problems with HMDs [2]. Specifically, in the study with which the results of spatial orientation skill from this workshop were compared [17], 50% of the participants felt dizzy, and 12% very dizzy during the experiment using HMD. We think it is important to know that desktop VR environments do not present these problems and can be an alternative to HMD if fatigue or dizziness occurs in the classroom.

Finally, item 10 told us about the loss of orientation in the created virtual environment. The average response to this item "During the workshop, when carrying out the navigation tasks in the virtual environment, I sometimes lost my orientation", was 5.88 ($SD = 1.59$). Numerous studies have reported disorientation as a factor associated with virtual environments [2,39,51].

6. Conclusions

In the strategy carried out in this research with a desktop VR environment, a perspective taking score gain of 11.36° (12.62%) was obtained, which was similar (without statistically significant differences) to that obtained with an HMD environment (12.81°, 14.23%). No gender differences were found in either case.

Therefore, environments based on virtual reality (both desktop and HMD environments) are equally valid for the development of spatial orientation skill. An important implication of this finding is that desktop VR environments can be an alternative to HMD-VR environments for planning strategies to improve spatial orientation skill in circumstances where HMDs cannot be used. These circumstances can be health related, as in the case of this research, with the restrictions required by COVID-19, although in teaching environments, there may also be economic limitations to acquire a large number of HMDs. In such cases, alternatives approaches such as students using their own computers can provide similar results for improving spatial orientation skill in VR environments.

One of the limitations of the present study was the limited number of participants, both in the workshop carried out here (25 participants, desktop VR-environment) and the workshop the results are compared to (32 participants, HMDs). This means that the results cannot be generalized, although they represent a starting point for future research involving more students.

Compared to other technologies such as augmented reality and geoportals, the gains with VR environments are lower. In this regard, it is worth asking whether this is due to the technology or due to the strategy used, as the greatest gains were obtained with combined strategies of navigation and map-learning tasks. In a future work, it would be interesting to study the effect of a combined navigation and map-learning strategy on the improvement of spatial orientation skill using VR environments, as a desktop VR environment allows the inclusion of auxiliary orientation elements such as maps or orthorectified views of the research area.

The results of the questionnaire confirmed that the desktop VR environment in the study was well perceived by the students. In a future work, it would be interesting to know the responses of the students to the same questionnaire after carrying out specific training to improve their spatial orientation skill using HMDs. In this way comparisons could be made, especially in aspects related to interaction, the sensation of movement, and fatigue and dizziness. In relation to the latter two factors, desktop VR environments are not only an alternative, but also a solution for those students who get fatigued and dizzy when using HMDs.

The present research, therefore, offers a starting point from which strategies to improve the spatial orientation skill of building engineers can be planned using desktop VR environments. Using the same measurement tool, the Perspective Taking Spatial Orientation Test, comparisons can be made among proposals to be developed. From an academic point of view, professional architecture organizations require higher education institutions to train students based on the acquisition of spatial skills, which are listed as competencies to be acquired in the STEM degrees of building engineering, landscape planning and engineering. The versatility offered by virtual reality technology allows the creation of different scenarios that can be specifically designed for the development of spatial skills, adapted to each academic environment.

Author Contributions: Conceptualization, C.C.-C., and J.L.S.; methodology, C.C.-C. and J.L.S.; software, J.L.S.; validation, C.C.-C., A.J.J. and J.L.S.; formal analysis, C.C.-C. and A.J.J.; investigation, C.C.-C.; resources, J.L.S.; data curation, C.C.-C. and J.L.S.; writing—original draft preparation, C.C.-C.; writing—review and editing, C.C.-C., A.J.J. and J.L.S.; visualization, J.L.S.; supervision, C.C-C, A.J.J. and J.L.S.; project administration, C.C.-C., A.J.J. and J.L.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the National Science Foundation, award #1956466 and by Spanish Ministry of Universities, Ministerial Order of June 18, 2021 calling, by advance processing, subsidies for 2021–2022 of the Mobility Subprogram. The 2020-1-ES01-KA203-082244 Project (Extended reality in biomedical settings) belonging to the European Erasmus + program has also partially funded this article.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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