Perceived Sensations in Architectural Spaces through Immersive Virtual Reality

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Abstract: To design architectural spaces that not only respond to the basic needs of users, but also seek their emotional well-being, it is necessary for the architecture students to have a special sensitivity and be aware of the different sensations that their designs should and can evoke. To achieve this competence without exploring real spaces, Immersive Virtual Reality technology offers an important contribution to the field of architecture. The purpose of this research is to determine if the sensations perceived in virtual architectural spaces by students are similar to the real ones and to determine the characteristics of this technology that allow a better perception of sensations. Six architectural modules were designed to be walked through and experienced at real scale using a Head Mounted Display by 22 students of the first and fifth year of studies of Architecture career in Peru. An ad-hoc questionnaire allowed to know the perceived sensations and the benefits of the tool. The results obtained showed that the perception of sensations of the fifth-year students is a little closer to those expressed by a group of seven experts compared to that of the first-year students. The students consider the characteristics of accessibility, real scale of the space and the possibility of going through and looking at the space in all directions are those that have given more realism to the experience and therefore better perception of the space, while the characteristics of natural light and shadows, construction materials and external environment have been less valued in the realism of the experience. It is concluded that the sensory experimentation in architectural spaces modelled realistically in virtual environments allows the perception of sensations very similar to those that the architect seeks to convey initially.

Keywords: Sensations; Perception; Architecture; Spaces; Immersive Virtual Reality.

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1. Introduction

Among the most important competencies that the future architect must acquire in university studies is the design of architectural spaces that not only respond to the basic needs of people, but also seek their emotional well-being. Architecture, beyond fulfilling the proper functioning of spaces, has the task of generating experiences and emotions in the inhabitant who appropriates the space. In this sense, it is essential that the architecture students develop a strong sense of sensitivity and commitment to spatial quality (Mitrache, 2013) that allows them to be aware of the different sensations that their designs should and can evoke in the users. The inhabitants of spaces perceive and understand architecture by living it and only from the interior experience can they feel the details imperceptible to the eye (Rasmussen, 2004). This link that architects have always explored between the built environment and the occupants (Li et al., 2020) can only happen thanks to the psychological phenomenon of perception.

1.1 The Perception

Perception is the means by which architectural space is experienced, understood as the artificial place where the existential nature of the human being is concretized (Norberg-Schulz, 1980). According to Keenan (Keenan, 2020) "perception is the organization, identification, and interpretation of sensory information, or information that is gathered through the senses, such as hearing, vision, taste, smell, and touch". Perception allows people to create meaning out of what they see, feel, hear, touch, and experience in the world. Then, only through perception, we can understand architecture as defined by Saldarriaga: "architecture consists of finding a meaningful relationship between the physical properties of architectural space and the psychological and cultural values that give rise to the senses of comfort, security, and beauty" (Saldarriaga Roa, 2002).

Psychology claims the active role of people in the construction of perceptual thinking (Arnheim, 1986), it means that people do not perceive the physical world, but the psychological construct that depends on their own relationship with the environment (Almagro Holgado, 2020), i.e., their previous experiences. Understanding that the process of perceiving is linked to the person, rather than the object (Dezcallar Sáez, 2012) and linked to personal experience and expectations (Keenan, 2020), we can affirm that we learn architecture with the experience of living it, and it is that same experience that we resort to when we analyse a space or project it (Gomes et al., 2017). However, the young student who starts studying the architectural space has not yet acquired such experience.

1.2 The Visual Perception

Every soulful experience in architecture is a phenomenon of multisensory perception (Pallasma, 2006), where each sense identifies different qualities of the space to be perceived, for example, sight and hearing allow to establish a broader relationship and distant experiences. On the other hand, touch, smell, and taste are interposed as capable of perceiving closer qualities. Finally, the corporeal relationship of the human being who experiences this space also intervenes in its perception. However, many authors agree with Arnheim (Arnheim, 1986) who expresses that of all the senses, sight is the preponderant one over the rest.

If we refer to the sense of sight, visual perception is the interpretation or discrimination of external visual stimuli related to the individual's previous knowledge and emotional state. Thus, visual perception allows to create and recreate in a sensitive and automatic way the information that the architect wants to capture in a project, and allows him to express his feelings, emotions and perceptions of the architectural space.

This ocularcentric position has generated negative effects in contemporary architectural production, reducing architecture to a visual advertising product that seeks only instant persuasion (Pallasma, 2006). However, this apparent disadvantage has been very well exploited by some emerging technologies such as Immersive Virtual Reality (IVR) that uses visual perception as the main sense to experience and perceive virtual architectural spaces in a very realistic way thanks to its possibility of immersion and the accompaniment of other senses such as hearing and haptic sense.

1.3 Teaching Spatial Perception

In university education, particularly in the field of architectural space design, there has been resistance to change in its pedagogical approaches and methods (Nisha, 2019). In the classical learning of space that happens in workshops; drawings, models and three-dimensional models are used to understand space and learn to perceive it. However, these ways of learning the perception of space are allocentric (in third person) and do not allow experiencing the space as it is, as it happens with egocentric learning, that is, when a person learns in first person by living and experiencing architectural spaces. The perception of a space has to do with the relationship of the body with the environment. This

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is reinforced by the other definition of perception which states that it is a process that makes a person aware of the relative position of his own body to the things around him and his relationships to them in terms of distances, sizes and orientation (Fieandt et al., 2007).

Therefore, the teaching of architecture and spatial perception is limited in developing students' strong sense of spatial engagement and their ability to relate to existing and imagined spaces through spatial sensitivity. If we insist that perception happens based on context, personal experience and expectations (Keenan, 2020) which allows a phenomenological construction of architectural space (Sánchez & Hessman, 2018) it is then recognized that the experience of living and experiencing space, is another way in which the student learns architecture, and appeals to that experience to analyse a space or project it (Gomes et al., 2017).

It is learning and spatial sensitivity developed early can guide students toward creating spaces as embodied experiences, rather than abstract constructions. Ideally, architectural design is a balanced combination of spatial intelligence (responsible for the solidity, coherence and cohesion of a projected space) and spatial sensitivity, which gives it a human, narrated and poetic dimension (Mitrache, 2013).

1.4   The Perception of Spaces with IVR

Immersive Virtual Reality, through the visual dimension of perception, in combination with the feedback of interactivity, can be useful to generate immersion, understood as the feeling of being present, even while one maintains a conscious awareness that it is only a digital model (Hermund et al., 2017). This condition coupled with a virtual environment provides a direct link between human perception and the environments we create making each person perceive their environment in a unique way, subconsciously overlaying their surroundings with information to create not just a literal space, but a "perceptual space" of their own (Holth & Schnabel, 2017)

Immersive Virtual Reality environments using high resolution Head Mounted Displays (HMD) and haptic controls can generate the aforementioned with full-scale spaces (Gómez-Tone et al., 2021) also due to the precision in the representation of materiality which together with the control tools for navigation in the environment confer a greater sense of presence to simulate architectural experiences and obtain a sensory perception of spaces in real time (Angulo, 2013). Such sensations are so intense that they can generate emotional responses with physiological changes (Roberts et al., 2019) that

are serving as indicators to measure human emotional experiences in architectural spaces (Shemesh et al., 2017, Ergan et al., 2019). These studies support the idea that virtual environments, could be considered as an alternative method when investigating the impact of stimuli that space features can provoke (Yeom et al., 2019, Kuliga et al., 2015, Homolja et al., 2020)

1.5   The Research Purpose

The first purpose of this research is to compare the sensations perceived within architectural spaces created in virtual immersive environments between first and last year architecture students and to determine whether they are similar to the sensations reported by the experts. And the second purpose is to determine the most relevant characteristics of the virtually created spaces that confer greater realism to the virtual experience to allow a better perception of sensations.

2. Methodology

For the experimentation, six modules of ephemeral architecture were designed, that is, architecture for the use of a spectacle or to become a spectacle in itself (Sánchez Vidiella, 2016) and which have the quality of configuring scenarios of greater architectural experimentation (Lizondo Sevilla et al., 2014). The spaces designed by architects of the research team and showed in Fig. 1 were assigned different materials, textures, colours, and natural lighting; they were then placed in a sequential path for visualization (Fig. 2). Each student, with the use of the HMDs, experienced each of the spaces, then their perceived sensations were recorded through ad-hoc questionnaires created for the experimentation.

For a more precise and real determination of the sensations that each space should provoke in the users, the opinion of seven experts was requested. They were five university professors of the subject "Architectural Design Workshop 1" and the two architects who designed the spaces. With their opinions, the predominant real sensations were established within a triad (alternatives) shown in Table 1.

2.1   Participants and Equipment

The participants in this study were students in their first and last year of studies at the Faculty of Architecture and Urbanism of the National University of San Agustin in Arequipa, Peru. We looked for a student archetype which characteristics were interest in video games and virtual reality, familiarity with computer technologies,
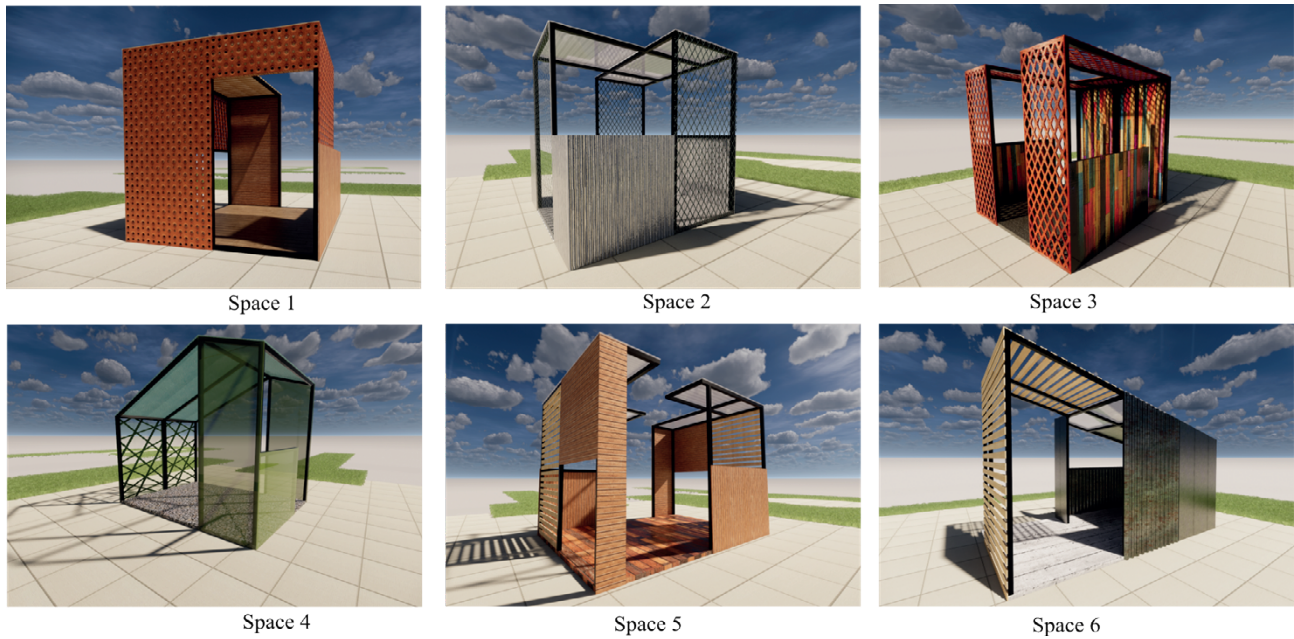
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Figure 1 | Architectural spaces to be perceived using IVR.

Figure 2 | Sequential path of architectural spaces to be perceived using IVR.

not suffering from vertigo, dizziness, migraines, and colour blindness, and not having experience with the use of HDM. Of the total of 146 students in these two subjects, 48 met the archetype. It was statistically

determined with a confidence level of 95%, heterogeneity of 50% and a margin of error of 0.1, that the required number of students was 16.

Twenty-two students were recruited, eleven from the first and eleven from the fifth year. The hardware used for the IVR experience consisted of a Personal Computer, 8 Gb RAM to which the Oculus Rift VR Headset with haptic controllers was connected. The architectural spaces were previously modelled in SketchUp Pro 2019 and visualized in the virtual reality app Enscape 3D version 2.6.

2.2 Measuring Instruments

To determine and measure the sensations perceived within the spaces experienced in the virtual world, an ad-hoc questionnaire was created for this study. The questionnaire was structured into five categories to group the various sensations (see Table 1).

These categories were: scale/size, building materials, architectural style, use/domain and degree of enclosure. For each category, three sensations that could be perceived were proposed, so the participants were asked which of the three sensations they perceived for each of the categories while experiencing the space with the HMDs. This same questionnaire was repeated for each of the six spaces.

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Table 1 | Categories and Sensations.

Categories	Sensations		
1. Scale and size	Restlessness	Balance	Grandeur
2. Materials	Warmth/comfort	Fragility/exposure	Distance/frigidity
3. Architectural style	Elegance/satisfaction	Simplicity/serenity	Eccentricism/surprise
4. Use and related activity	Joy/theatricality	Sadness/nostalgia	Emotion/spirituality
5. Degree of enclosure	Protection	Calmness	Freedom

To determine the most relevant characteristics of the IVR that allow the best perception of the sensations, participants were asked after touring the six spaces to rank the following six characteristics from the most to the least relevant: the building materials, the possibility of entering the space, the possibility of looking everywhere, the real scale or size of the space, the outdoor environment, and the natural light and shadows.

2.3 Experimental design

An initial contact was made with all the participants to learn their general data, to obtain their informed consent and to inform them of the dates and schedules when they would have to come individually to carry out the experiment.

Only one 45-minute session was required for each participant. The first 15 minutes were used to practice and familiarize themselves with the HMD, the immersive virtual reality environment and the haptic (handheld) controllers to move around in the virtual space. Once inside the virtual environment and for approximately 30 minutes, the participant virtually visited the designed tour to perceive the six designed spaces. The participant walked autonomously through the pedestrian path (see Fig. 2), being able to look everywhere, bend down, turn around and move directly to any point in order to appreciate the space from the outside and from the inside, as well as the materials, shapes and dimensions.

The participants were not allowed to rise to see the spaces by flying over them; we wanted to have the same real conditions of perception of the space by walking.

Once inside each of the six spaces, the participant was offered to stand or sit in a real chair to better experience the space and answer the questions of the ad-hoc questionnaire. created to obtain information on their perceived sensations. Thus, the participant was asked to choose one sensation from a triad of each of the five categories shown in Table 1.

3. Results

The following figures (Figures 3 to 5) compare the sensations perceived by the first- and fifth-year participants in each of the six perceived spaces in an IVR environment with the sensations expressed by the experts.

In space 1 (Fig. 3) the experts were unanimous in the perceived sensation of the first two categories, and it was the fifth-year students who were closest in their perception. In the next three categories there was no unanimity of the experts, however, again the fifth graders were closer to the experts' opinion.

The category in space 1 that in general terms showed the closest approximation of student sensations with experts was "materials".

In space 2 (Fig. 3) the perception of sensations of the fifth-year students is again closer to those expressed by the experts. Only in the fourth category it is found that the perceived sensations are equally close in both groups. The sensations in the categories that have come closest to those expressed by experts have been "scale and size" and then "architectural style".

In space 3 (Fig. 4) shows us that, in the materials category, this time it is the first-year students who perceived the sensations in 100% correspondence with that expressed by the experts. In the rest of the categories, again the sensations perceived by the fifth-year students when they used an HMD were closer to the sensations expressed by experts. In this space, it was the category of "materials" and "use and related activity" in which the students expressed sensations closest to those of the experts.

Space 4 (Fig. 4) shows that the experts did not have a unanimous opinion in the first four categories. However, the fifth-year students again come closer to these sensations in spite of being two different sensations in the same category. For this space the category of "materials" shows more approximation of sensations of the students with respect to the experts.
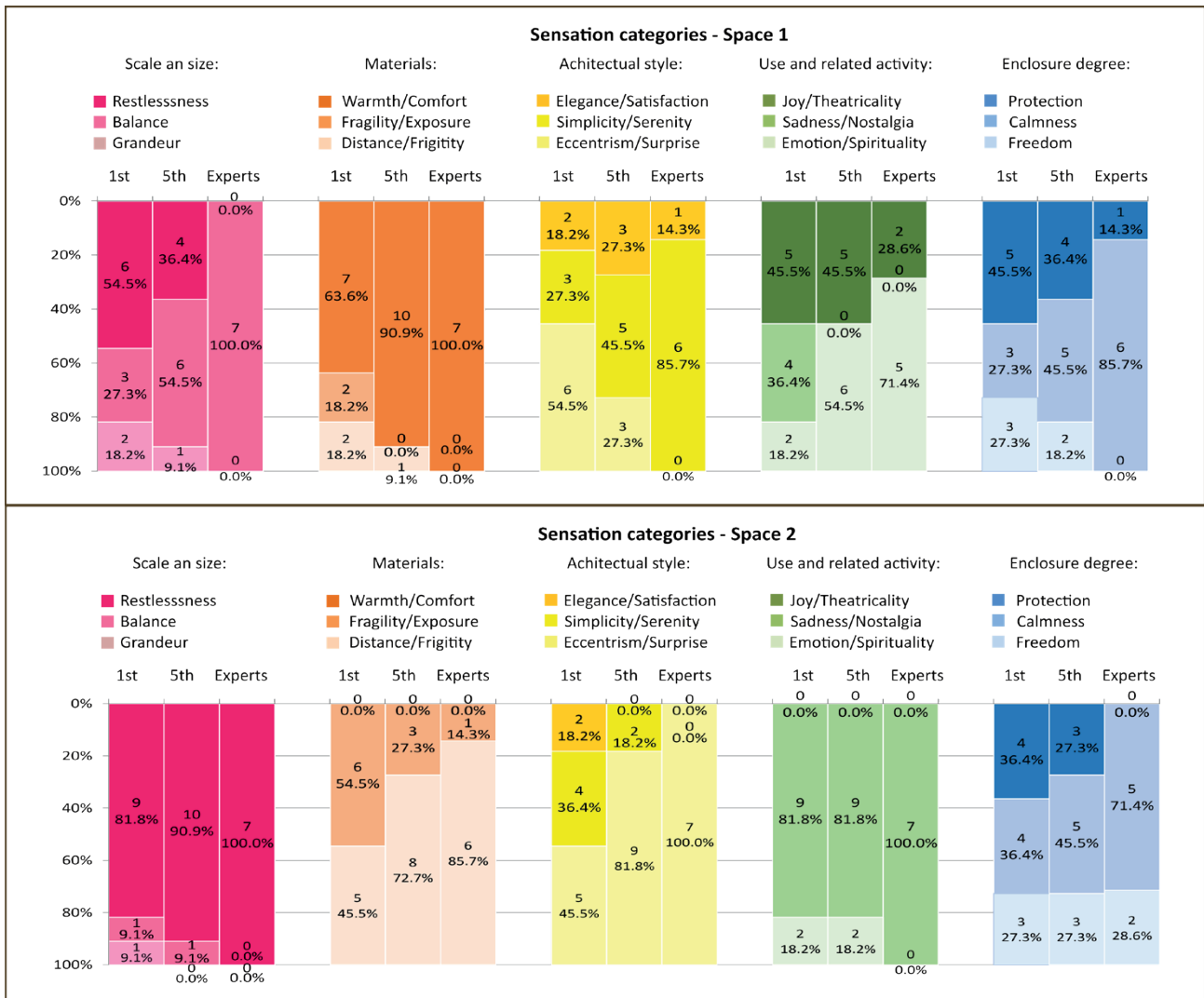
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Figure 3 | Sensations perceived in Space 1 and 2 using IVR (1st- 5th students and experts).

Unlike in the rest of the spaces, in this fifth space (Fig. 5) it is the first-year students who in three categories have come closest to the sensations expressed by the experts, even in one of them, the category of architectural style, the correspondence has been 100%. Something very similar to what was appreciated in space 2. In this space the sensations in the categories that have come closest to those expressed by experts have been "scale and size" and "architectural style".

Finally, Fig. 5 shows that in the last space only in the category of materials, it is the first-year students who, in percentage terms, are closer to the sensations expressed by the experts. In the remaining four categories, the fifth-year students have shown that their perceptions of

sensations are similar to those of the experts. In this last space, the sensations evoked by the "materials" and then by the "architectural style" are the categories that show the most similarities between students and experts. In the last part of the ad-hoc questionnaire applied to the students, they were asked to rank six characteristics that could have greater relevance in the realism of the experience of perceiving each of the six architectural spaces. The votes obtained from the 22 students had very little variation by group as seen in Fig. 6.

The results show that accessibility, expressed as the possibility of entering and leaving the space at will, is the feature most valued by the architecture students with 59 and 58 points. The second and third most valued
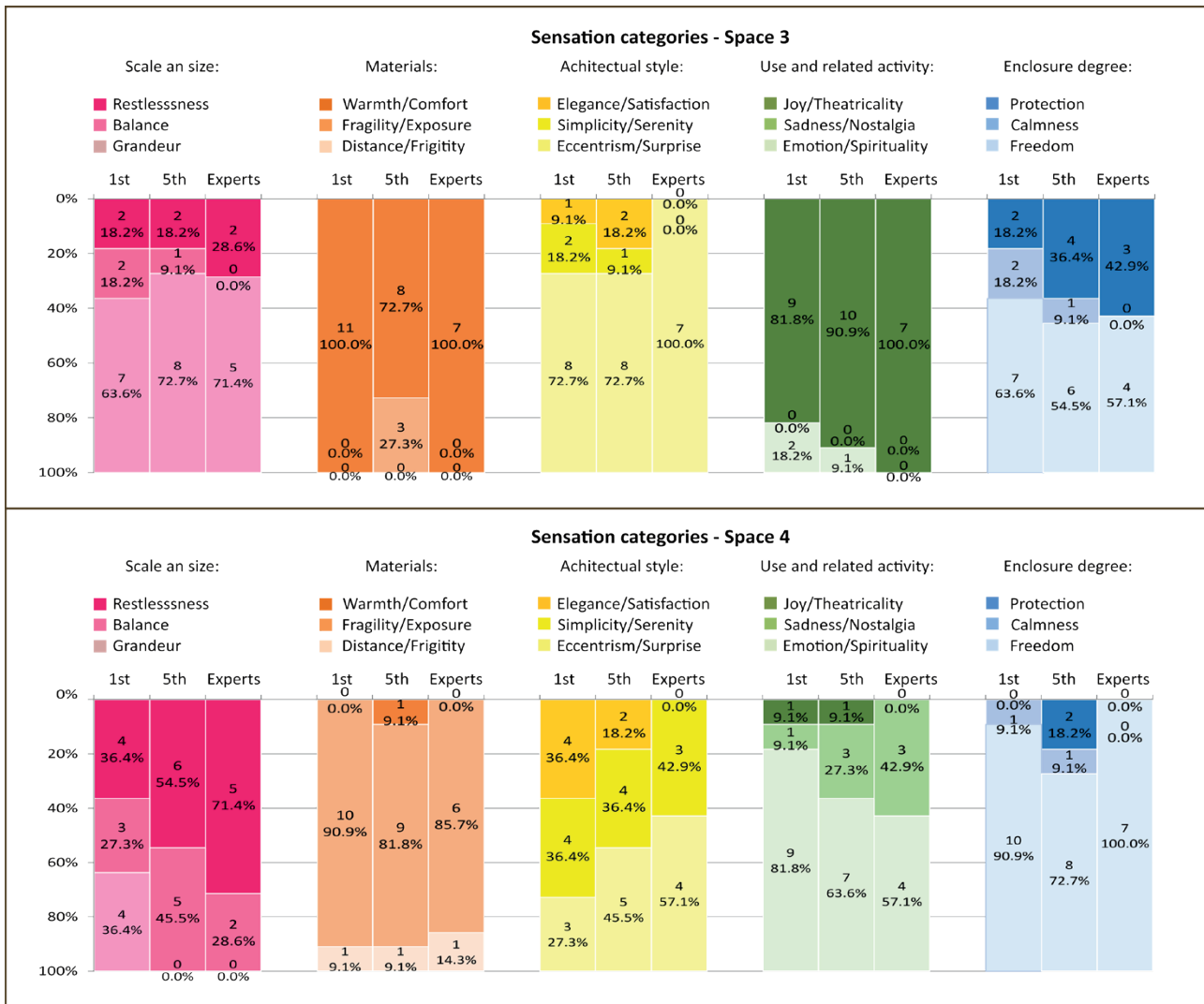
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Figure 4 | Sensations perceived in Space 3 and 4 using IVR (1st- 5th students and experts).

characteristics were the real scale of the architectural space (54 and 51 points) which is related to the previous one because a person, only at real or natural scale, can enter a space; and the possibility of directing the gaze in any direction to better recognize the space (50 and 48 points).

The least valued characteristics were the natural daylighting of the environment and the shadows (29 and 25 points), then the materials that were very realistic (23 and 22 points).

Finally, the characteristic that in the opinion of the students had the least influence (22 and 21 points) on the lived experience was the surrounding environment that in this case was an almost infinite flat terrain with a

sidewalk for the tour and a blue sky with some clouds as can be seen in Fig. 1.

4. Discussion

The high approximation of the students' sensations perceived in the spaces built in IVR, but not an exact match with the experts' opinion, may be due to the fact that the process of perceiving is more linked to the person than to the object (Dezcallar Sáez, 2012) and it depends on personal experience and expectations (Keenan, 2020). In this way IVR has created a direct link between students' perceptions and the experienced environments resulting in their own "Perceptual Spaces" (Holth & Schnabel, 2017).

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Figure 5 | Sensations perceived in Space 5 and 6 using IVR (1st- 5th students and experts).

On the other hand, sensations have been categorized for measurement and experimentation purposes, but in the real world, sensations are perceived as the sum of all features of the virtual space. Also, it can be added external conditions such as the excitement and surprise that students may have felt because of their own experience of using the technological tool for the first time. This explains, for example, that "magnificence" was reported in space 1 as a sensation, when this type of sensation occurs mainly in very wide and high spaces and not in small spaces as in the experiment. It may also be due to a misunderstanding of the concept of some sensations.

Regarding the sensation categories, it was found that the sensations evoked by the category of materials

(warmth/comfort, fragility/exposure and distance/frigidity), have had greater coincidence between the opinions of the students and the experts, it means that the realism of the materials allows the sensations to be experienced in a better way. On the contrary, the sensations caused by the category of degree of enclosure (protection, calmness and freedom) in the virtual world are the sensations that have had less agreement between students and experts. It is worth mentioning that in this category, the experts have had greater discrepancies in terms of the perceived sensations, which could explain the greater misconception of students who have less experience and less achieved the spatial perception. In general, the virtual spaces created have allowed students to recognize sensations very similar to those that the
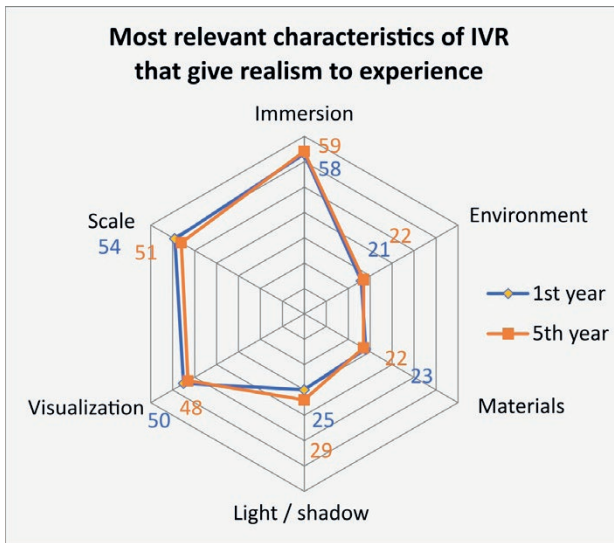
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Figure 6 | Most relevant characteristics of IVR that give realism to experience.

experts proposed as the most relevant and that should be the sensations experienced in the physical world. This finding is important and necessary because it will allow to assess the quality of spaces in a pre-occupancy manner and to check if the final usability of an architectural space has been achieved prior to its actual construction offering qualitative information about the performance of buildings (Moloney et al., 2019 Ergan et al., 2019).

On the other hand, the fundamental concept for understanding and evaluating the effectiveness of virtual environments primarily in the context of human experience (Ghani et al., 2020, Alatta & Freewan, 2017) is the sense of presence (Hermund et al., 2017) -subjective sensation of feeling present in another place- which is determined by immersion and realism. Students have reported that, in the case of perception of architectural spaces, unlike other three-dimensional objects, the immersion and realism is mainly contributed by "accessibility" (possibility to enter and exit the space at will), "real scale" (natural size of the space) and the "possibility to see in all directions". These three characteristics are over and above the realism of materials, natural lights, and shadows, as well as the external environment. It may seem a contradiction that the materials have not contributed much to the perception of realism of the spaces, but they have made them as the category that had more coincidences of sensations between students and experts, however they are two different aspects.

The methodological implication that emerges from the research is the incorporation of IVR in the learning process of architectural space perception in the undergraduate architecture course. The fact that IVR can offer an egocentric experience of space in its real dimension shows the potential for experiential learning of spatial perception as the learner leaves the allocentric spatial frame to be in an egocentric spatial frame and experience the spatial qualities (Nisha, 2019). A limitation found in the study is the little possibility of bringing the IVR experience to the academic and didactic field in a massive way since in developing countries there is a restricted technological accessibility that added to other factors such as the ease of use and interface of the programs and applications move this technology away from the students. (Brandão et al., 2018).

5. Conclusions

The sensory experience of architectural spaces built realistically in IVR using an HMD allows to perceive in a very approximate way the same sensations that the architect initially sought to convey. This has been demonstrated by the coincidence of the sensations perceived by first- and fifth-year architecture students when interacting with the six spaces in an immersive virtual environment. On the other hand, the perception of sensations of the fifth-year students compared to those of the first year is closer to that expressed by the experts. The introduction of this tool is very useful for learning the perception of architectural space as it will allow students from the first year to design spaces meeting sensory expectations.

On the other hand, of the various advantages attributed to the IVR, the possibility of entering and leaving the space at will (accessibility), the real size of the space (scale) and the possibility of seeing in all directions without restrictions (visualization) are the three characteristics that confer greater realism and immersion to the experience of perceiving a small architectural space.

A comparative study between the perception of real spaces (digitally fabricated) and the perception of the same space in IVR will be proposed as a future research line, using portable devices capable of capturing brain waves that give us a complementary approximation of the perceived sensations to be contrasted with those expressed in questionnaires and thus provide guidelines and practical criteria for architects and designers to incorporate emotions in their designs (Maghool et al., 2020).

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This work involves an incipient line of research and development work. This project is currently working on the perception of space and form in more complex buildings, analysingsensory stimuli and measuring brain activity during a virtual stay in architectural spaces.

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