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PAPER

Augmented Reality for the Development and Reinforcement of Spatial Skills: A Case Applied to Civil Engineering Students

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ABSTRACT

The architecture, engineering, construction, and operation (AECO) industry has brought transformations within the field. Despite the changes, traditional teaching methods such as analyzing two-dimensional plans and models are still being used in training processes, which do not effectively promote the development of spatial skills. In this context, augmented reality (AR) can be used as a tool to translate two-dimensional information into three-dimensional space. Thus, the present study explores the use of the *VT-Platform AR* tool to develop and reinforce spatial skills among undergraduate civil engineering students. The study follows a quantitative approach with a descriptive scope and an experimental design. Students in the sanitary engineering subject were divided into two groups: an experimental group and a control group. A short-term teaching-learning methodology was proposed for the experimental group using the *VT-Platform AR* tool. Both groups took the differential aptitude test (DAT) to measure their spatial skills. The experimental group showed a higher average score compared to the control group, with a difference of 29.8%. Furthermore, the use of the *VT-Platform AR* tool helped standardize the level of spatial skills within the experimental group. It was concluded that using the *VT-Platform AR* tool can effectively develop and reinforce spatial skills among students.

KEYWORDS

spatial skills, experiential learning, engineering curriculum, augmented reality (AR)

1 INTRODUCTION

Currently, higher education programs face the challenge of staying up-to-date by responding to the processes of globalization and internationalization that define international quality standards [1]. In this context, UNESCO [2] declares that higher education programs should base their training processes on competency-based curricula. This approach prepares students to successfully adapt to changing professional and personal contexts, enhancing lifelong learning (LL) [3].

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Certainly, educators are dedicated to enhancing the learning potential of each student, enabling them to acquire, reinforce, reconstruct, and apply the essential blend of knowledge, skills, attitudes, and values to successfully tackle environmental challenges [4]. Competency-based curricula, which rely on learning-centered models, are designed to develop specific and generic competencies [5].

In this context, competency-based curricula should respond to society's demands by ensuring the training of competent and competitive professionals in each knowledge field [3]. Thus, they should be constantly revised and updated according to the evolution of each discipline. This revision and update should also encompass the relevant curricular components, such as admission and graduation requirements, training areas, study plans, teaching methods, assessment strategies, technology and infrastructure, and faculty profiles [6].

In the case of the AECO industry, the fourth industrial revolution, or industry 4.0, has brought transformations within the field, such as the introduction of new methodologies, workflows, and technologies [7]. Therefore, every civil engineer requires a certain set of knowledge, skills, attitudes, and values for professional development. Learning discipline-specific concepts such as construction processes, elements of a building, architectural design, section cuts, and elevations is essential in the training process of future engineers [8, 9, 10].

Nevertheless, despite the changes within the AECO industry, traditional teaching methods, which are based on analyzing 2D plans and models, are still being used [11]. In fact, simplified drawings, presentations, and materials such as pencils, paper, and graphics are used to represent discipline-specific concepts. For engineering students, this information transmission method is limited due to the abundance of information [12] and their varying understanding capacities, which hinder the proper communication of the original message [13]. Additionally, these traditional methods fail to cultivate motivation in students [14, 15, 16]. Consequently, if there are difficulties with interpretation, educators should provide students with a wider variety of tools to enhance their understanding [17].

In fact, literature suggests that students have difficulties understanding the structural elements that make up a building through two-dimensional representations because they struggle to interpret the information in three dimensions [18, 19, 20]. The ability to generate a mental image in two or three dimensions from a visual stimulus is possible due to spatial skills [21]. Spatial skills enable students to mentally manipulate objects and their components in both two-dimensional and three-dimensional spaces [22]. Spatial skills consist of spatial perception, spatial visualization, mental rotation, mental relationships, and spatial orientation [23]. Among these, "visualization," the ability to handle complex shapes, is the component most closely associated with civil engineering training due to its connection with graphic communication related to design [24]. In addition, it allows students to create images to perform engineering tasks more fluidly [25].

Therefore, technology-enhanced teaching should be adopted because it increases the effectiveness of the educational process and enables teachers to provide a high-quality education [14, 26]. This type of teaching, which includes experiential techniques such as virtual reality (VR) and augmented reality (AR), is reported to motivate students while allowing them to build knowledge alongside the teacher [18]. Certainly, Sorby [27] indicates that the utilization of VR and AR enables an effective teaching environment for the enhancement of spatial skills. This is because the use of these technologies involves visual-motor coordination. Furthermore, VR and AR facilitate a better understanding of discipline-specific concepts as they involve fewer symbols to interpret [17]. In this study, Gómez-Tone et al. [28] utilized an AR-based training course to significantly enhance spatial skills in a cohort of engineering students. Similarly, Roca-González et al. [30] and Martín-Gutiérrez et al. [31] conducted successful studies utilizing an AR book.

Virtual reality aims to create an artificial world where the user can interact with virtual elements, while AR complements the real world by establishing physical objects in the user's environment as a background and overlaying computer-generated information [32]. According to the literature, AR is a better tool than VR for teaching within the construction field because it does not completely isolate the user from reality; instead, it adds information and enriches the learning experience [33, 34]. On the other hand, AR provides immersive and realistic learning experiences that enable the creation of learning environments conducive to inclusive and collaborative learning [35, 29]. Likewise, it helps break down the barriers of formal education and supports high-quality education at any location and time [36].

Thus, this study aims to propose a teaching-learning methodology utilizing an innovative and intuitive didactic tool that involves experiential technology, specifically the *VT-Platform AR* tool. This tool enables the development and reinforcement of spatial skills, thereby facilitating discipline-specific understanding among a group of undergraduate civil engineering students. To achieve this goal, a research question was formulated as follows: How can spatial skills be developed and consolidated within a group of civil engineering students using augmented reality?

It was expected that the proposed tool would be easy for students to access and use, thereby facilitating their understanding of the structure of sanitary systems. This specialty was chosen because, as reported by Penadillo et al. [37], sanitary engineering has the highest percentage of students who did not pass (76%). Likewise, it is considered that this research is related to the Sustainable Development Goals (SDGs) as it aims to propose a methodology for developing and enhancing spatial skills among civil engineering students. This will not only improve their learning process but also prepare them for successful careers in the future, enabling them to create value for society.

2 CONCEPTUAL FRAMEWORKS

2.1 Spatial skills

Spatial skills do not have a single definition. Lohman [38] defined spatial skills as the mental ability to generate, retain, retrieve, and transform well-structured visual images. Sánchez and Reyes [39] explained spatial skills as the ability to perform mental spatial tasks that can be developed through learning, practice, and acquired experience. Saorín [40] defined spatial ability as "the ease of mentally rotating, manipulating, and visualizing two- and three-dimensional objects," while Tristancho-Ortiz et al. [41] referred to spatial skills as a component of intelligence, associated with the capacity to create a mental geometric representation of the world. Spatial skills can be defined as the ability to create a mental image, rotate and manipulate it, and remember any alterations made to it. Thus, spatial skills enable students to mentally manipulate objects and their components in two-dimensional and three-dimensional spaces [22].

Spatial skills consist of several components, the number of which may vary according to each author. On the one hand, Murphy [42] recognized two components: visual coordination speed and spatial relations; Thurstone [43] identified a single component, which he called "space"; Zimmerman [44] recognized two components, spatial dimensions and visualization; and French [45] also acknowledged two components, visualization and orientation. On the other hand, Guilford et al. [46] identified five components: spatial relations, visualization, spatial orientation, spatial exploration, and perceptual speed. In contrast, Linn and Petersen [47] focused on only three components: spatial perception, mental rotation, and visualization. Likewise, Lohman [38] recognized five components: visualization, rotation speed, closing speed, closing flexibility, and perception speed. Finally, Saorín [40] recognized that spatial skills have two components: spatial relationships and spatial vision. The first skill involves performing rotations and comparisons of two-dimensional and three-dimensional cubes, while the second skill involves recognizing three-dimensional shapes by folding and unfolding their faces. Table 1 presents the components shared by the various authors mentioned.

Table 1. Components shared by the authors

	Murphy (1938) [42]	Thurstone (1938) [43]	Zimmerman (1953) [44]	Thurstone (1950) [48]	French (1951) [45]	Guilford, Fruchter and Zimmerman (1952) [46]	Linn and Petersen (1985) [47]	Lohman (1996) [38]	Saorín (2008) [40]
Visual-motor coordination speed	X								
Spatial relations	X		X	X	X	X			X
Component "Space"		X							
Visualization or spatial vision (Recognize the identity of an object from different angles, imagine internal movement between the parts of a total configuration.)			X	X	X	X	X	X	X
Spatial Orientation						X			
Space exploration						X			
Spatial perception and perceptual speed						X	X	X	
Mental rotation and rotation speed							X	X	
Closing speed								X	
Closing flexibility								X	

As seen in Table 1, authors such as Zimmerman [44], Thurstone [48], French [45], Guilford et al. [46], and Saorín [40] recognize spatial relations and visualization as essential components of spatial skills. There are various tests that seek to measure spatial skills through their components, such as the spatial relation subset of the primary mental abilities test (PMA-SR) [43], the mental rotation test (MRT) [49], and the mental cutting test (MCT) [50], among others. However, according to Saorín et al. [22], in the engineering field, the most commonly used tests are the MRT, as shown in Figure 1 [49], and the spatial relations test of the differential aptitude test battery, or DAT-SR, as demonstrated in Figure 2 [52].

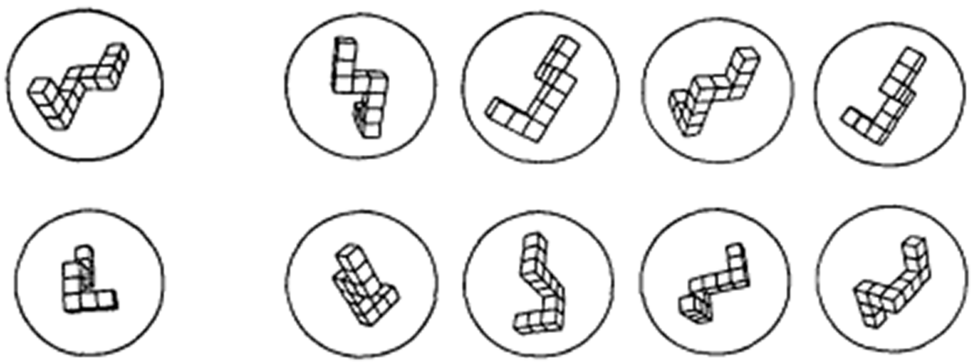

Fig. 1. Mental rotation test (MRT)

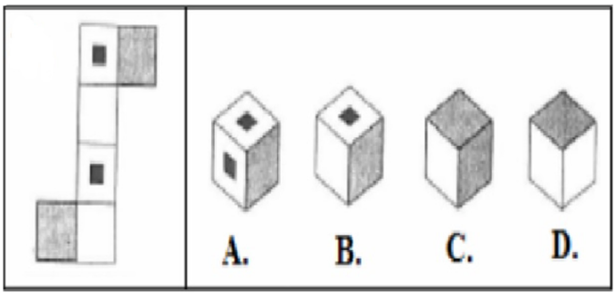

Fig. 2. Differential aptitude test-spatial relations subset (DAT-SR)

According to Ferguson [52], spatial skills are usually intuitively related to the engineering field. Engineers, regardless of their field, will always have to create, interpret, and validate drawings, which typically depict three-dimensional elements. Furthermore, the acquisition of spatial skills enables engineers to visualize objects in various orientations, manipulate three-dimensional models, and mentally reconstruct two- to three-dimensional drawings on paper or computer-aided design programs. Spatial thinking is also essential for scientific reasoning, as it involves representing and manipulating information in problem-solving [23, 53, 54].

Therefore, it is essential to ensure the development of spatial skills in engineering undergraduate students. In fact, within the student outcomes (SO) proposed by the Accreditation Board for Engineering and Technology [55], the ability to apply engineering designs to produce solutions that satisfy specific needs is considered necessary. This ability requires the development of spatial skills. Within the project design area, civil engineers are responsible for creating, interpreting, and validating drawings that represent three-dimensional elements [56]. On the other hand, another SO proposed by ABET [55] is the capability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. This statement has a significant connection to the findings of Adánez & Velasco [25], who argue that spatial skills are linked to the development of students' ability to abstract and can enhance their problem-solving capabilities.

Nevertheless, despite the importance of spatial skills in the engineering field, the literature reports that students are not able to develop them properly. For instance, Ospina and Lara [57] showed that students experienced issues with rotation problems. Gómez [58] and Fogarty et al. [59] found that students had a low level of spatial skills, particularly in the visualization component. Arguello [60] suggested that engineering students have major shortcomings in understanding the spatial relationships of objects within their environment. In short, studies indicate that students have difficulties mentally manipulating objects and their parts in two-dimensional and three-dimensional spaces [25]. Few people can visualize discipline-specific terms like a "separator (concrete die)," reinforcements in reinforced concrete beams, and buckling in steel elements [59, 61, 62].

According to Bravo et al. [56] and Alias [63], teaching-centered models are common in subjects like engineering drawing and structural design, where students enhance their spatial skills. These models limit students to observing the teacher's explanations and demonstrations, which rely on primitive tools such as markers, chalk, paper, pencils, and solid models. Thus, teachers are positioned as the protagonists in the teaching-learning process, while students are marginalized [64]. These models use the master lesson and oral presentations as the main teaching methods [65]. Consequently, there is little interaction between the students, the objects, and the operations required to rotate these objects and view them from different perspectives. Furthermore, these models lead students to memorize a set of rules to carry out representations instead of facilitating a knowledge-building process [66].

Thus, learning-centered models should be encouraged because they promote collaboration between students and teachers to build knowledge together while developing fundamental skills, attitudes, and values. At the same time, the knowledge acquired can be utilized in everyday life to comprehend the environment, rather than solely focusing on exam success [67]. Therefore, these models advocate innovative teaching methods that encourage active student participation, such as problem-based learning (PBL), where a real-life problem is used as the starting point for learning [68]; project-based learning (PrBL), where students learn by dealing with unexpected problems while developing real-life projects [11]; research-based learning (RBL), where students learn by becoming research agents [3]; or experiential learning, where concepts are constructed through well-designed learning experiences [69]. These teaching methods provide students with the opportunity to engage in their own learning process [67]. In this context, AR stands out as an example of experiential learning.

2.2 Augmented reality

Azuma [70] defines AR as a variant of VR where the user can see the real world mixed with superimposed virtual objects. Similarly, Domínguez and Luque [71] agree that AR is a type of VR that artificially stimulates users' senses, primarily sight, by adjusting and superimposing objects in the real world. Milgram et al. [72] and Drastic and Milgram [73] define it as a type of mixed reality that enhances natural feedback for users through computer-simulated signals. Table 2 presents the organization of categories and common points by author.

Table 2. Organization by categories and common points identified by author

	Concept				User Experience			Transmission Time
	Variant of Virtual Reality	Mixed Reality Type	Middle Ground Between the Virtual Environment and Telepresence	Integrating System	The Mixture Between Superimposed Virtual Objects and Reality is Visualized	Artificial Stimulation of Senses (Mainly Vision) by Computer Signals	Virtual Objects are Aligned and Adjusted	Live
Azuma (1997) [70]	X				X			
Dominguez and Luque (2011) [71]	X				X	X	X	
Milgram et al. (1995) [72]; Drascic and Milgram (1996) [73]		X				X		X
Milgram and Kishino (1994) [74]			X					
Höllerer and Feiner (2004) [32]				X	X		X	X

In this line, Milgram and Kishino [74] consider that AR is the "middle ground" between the virtual environment (completely synthetic) and telepresence (completely real). Finally, Höllerer and Feiner [32] define AR as a system that integrates real and computer-generated information in a live, interactive manner within a real environment, aligning virtual objects with physical ones. Table 2 summarizes the key points of each concept and the shared points among the authors.

As shown in Table 2, both Azuma [70] and Dominguez and Luque [71] agree that AR is a variant of VR. In addition, along with Höllerer and Feiner [32], they all examine the user's experience with AR and the integration of virtual objects with reality. Accordingly, Höllerer and Feiner [32] state that for AR to function effectively, the following components are essential: a computer platform, screens, registration of physical objects, wearable input and interaction devices such as glasses, gloves, headphones, or helmets, wireless networks, data storage, and modeling of the environment.

Cadavieco, Sevillano, and Amador [75] indicate that there are three types of AR: based on trigger patterns (markers), where specific images (such as images, drawings, or barcodes) are recognized and activate the operation of an application; based on geolocation, where AR accurately locates the user anywhere on earth through the global positioning system (GPS) on their portable device; and based on interaction with the internet, where captured images are matched with similar ones in internet databases.

Because of the aforementioned characteristics, AR has been used for various applications such as teaching science, geometry, astronomy, medical and health education, and anatomy [76]. According to Cubillo et al. [77], Radu [78], Han et al. [79], and Akçayır and Akçayır [80], teaching with AR enriches the information to make it more understandable. It can be used at different levels of teaching, in various subjects, and across disciplines. Furthermore, using AR for student training reduces training time, increases the quality of education, strengthens the practical aspect of the educational process, and stimulates students by capturing their interest [81]. Finally, it also encourages more flexible and interesting learning environments, willingness and motivation to learn, active dynamics during learning processes, and collaborative and decontextualized learning [82, 77, 78, 79, 80].

In this context, the literature reports that authors have designed AR tools to enhance teaching and learning processes. For example, Ismail et al. [83] designed an AR teaching kit that includes animations, games, and explanatory videos for welding instruction [84]. Coma et al. [85] developed the FI-AR learning application, which is designed to generate educational content using AR in the desired area by the educator. The application allows for content editing. Kerr & Lawson [86] developed a prototype using AR to educate first-year students, who have no prior design knowledge, about the principles of landscape architecture. Fernandes et al. [87] developed a mobile application with AR for studying the spinal cord. The app allows interactive exploration of 3D rotating models on a macroscopic scale. Similarly, Martín-Gutierrez et al. [88] applied AR to enhance engineering students' drawing skills by 31.8%, while Tiwari et al. [89] utilized AR to significantly enhance the drawing skills of low-achieving engineering students by 92.1%.

This variety of experiences reveals that, in terms of viability, AR is becoming easily adoptable by higher education institutions. In fact, since 2014, technology companies have been developing wearable input and interaction devices that are more efficient and affordable. Furthermore, this adoption may be further supported by evidence indicating that learning through VR and AR increases learners' level of attention by 100%, enhances their test results by 30% [17], and improves their spatial rotation and visualization ability by 87%. This makes the investment an institutional and educational opportunity for improvement [90].

3 METHODOLOGY

3.1 Context

This study was conducted in an undergraduate civil engineering program at a private higher education institution in Peru. This program is characterized by the implementation of a methodology, the gradual implementation research competencies (GIRC) program, which allows students to develop and reinforce research competencies gradually and across disciplines [3]. Additionally, it includes a building information modeling (BIM)-related curriculum that emphasizes training in civil engineering discipline-specific competencies [7].

Among these discipline-specific competencies, spatial skills, along with knowledge, attitudes, and values, are required to successfully perform the assigned tasks throughout the curriculum. Thus, within this context, the present research aims to develop a teaching-learning methodology using an AR tool to positively impact the development and consolidation of spatial skills among students.

3.2 Design and participants

This study adopts a quantitative approach by utilizing data collection to test hypotheses based on numerical measurements and statistical analysis. This approach aims to establish behavioral patterns and validate theories. The design is experimental, as the independent variable, the AR tool in this study, is intentionally manipulated to measure its effects on the dependent variable, spatial skills, within a controlled situation. Finally, the scope is descriptive because the purpose of the study is to describe how spatial skills are affected when applying the AR tool [91]. The dimensions, components, and indicators of these variables are detailed in Table 3.

Table 3. Dimensions of the variables, indicator and corresponding items

Variable Type	Variable Name	Dimensions	Indicators
Independent variable	Augmented reality	Informatic platform	Performance
			App stability
		Input devices	User comfort
			Navigation
		Environment modeling	Quality of the visual environment
			Structure and organization of the app
		Data storage and access technology	Consistency of information with the course
			Relevant information
Dependent variable	Spatial skills	Spatial relations	–
		Visualization	–

Regarding the universe and sample, to establish the relationship between the AR tool and spatial skills, students from the Sanitary Engineering subject in an undergraduate civil engineering program were selected. Every student enrolled in this subject during the academic semester in which the study was conducted participated, so the population and sample matched in this study. This subject was chosen because, as demonstrated by Penadillo et al. [37], sanitary engineering has the highest percentage of students who did not pass (76%). Accordingly, the student sample is non-probabilistic; specifically, judgment sampling was applied. The sample was chosen based on students' enrollment in the Sanitary Engineering subject.

Additionally, the study included two groups of participants, each consisting of 20 students. For the experiment, the room was divided into two groups: the experimental group, which had access to the tool, and the control group, which had no access to it.

3.3 Data collection techniques

AR Tool. The VT-Platform AR tool is a mobile application compatible with Android and iOS that enables users to view and interact with BIM models in AR and VR. The added value of the tool is that it allows users to obtain instant information about the construction elements and understand, in a more intuitive way, the operation of the systems. The formats supported by the tool are: ifc 2×3, fbx, obj, glb, pdf, txt, doc, docx, xls, and xlsx. The VT-Platform AR tool has not been utilized in research yet. However, it has been used in a variety of private Spanish projects, contributing to their visualization and management. In addition, it has the endorsement of recognized multinational companies such as Schneider Electric, Saint-Gobain, Ferrovial S.A., and Engie Energía, among others. Additionally, it has the support of communities such as BIM & Co., Bim Channel, and Bimetica, among others.

For this study, the sanitary systems and water and drainage from a pavilion at the Peruvian private higher education institution were modeled and synchronized with the tool, as shown in Figure 3. Figure 4 presents a reference image from the VT-Platform AR tool. Students' experimentation with the tool was carried out through a direct and short-term teaching-learning methodology. The development time of 120 minutes was determined considering the studies conducted by Fernandes et al. [87], Quintero et al. [92], and Castellano and Valencia [93].

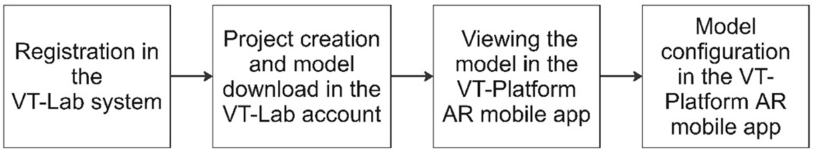

Fig. 3. Flowchart for tool configuration (App with AR)

Fig. 4. Reference image of the VT-Platform AR tool

Spatial Skills. To measure the spatial skills within the selected group of students, the differential attitude test (DAT) was used [51]. DAT is a battery of eight tests that measure skills in verbal reasoning, numerical reasoning, abstract reasoning, spatial relations, mechanical reasoning, spelling, sentence structure (grammar and writing), speed, and perceptual precision. DAT presents two levels of increasing difficulty: level 1 is applicable for ages twelve to sixteen (secondary student level), and level 2 is designed for higher-level and adult training cycles. Consequently, considering the context of the study, level 2 was applied.

It should be considered that although the area referred to as spatial relations is utilized in the test, what is actually quantified is the visualization component of spatial skills. This is because the DAT necessitates the manipulation of complex information, which is the area most closely associated with civil engineering [24]. DAT measures spatial visualization by creating 3D mental images from a 2D display. It consists of 50 closed questions, where figures are displayed on the left (2D display) and four alternatives are presented on the right (3D models). There is only one correct option. Each correct answer is equivalent to one (1) point, with fifty (50) points being the maximum score [51].

According to Bennett [94], the DAT has a reliability coefficient of 0.9 for the higher-level and adult difficulty in the spatial relations section. As for its validity in higher education, the DAT is used to predict the results of university entrance tests and forecast professional and educational success [95, 51].

Experimentation. The data collection process consisted of two phases: in the first phase, the experimental group was given access to the VT-Platform AR tool, while the control group used the DAT. Subsequently, in the second phase, the experimental group took the DAT, while the control group was provided access to the VT-Platform AR tool. The use of the tool was timed: students were given 10 minutes to enter the tool, configure it, and learn about its interface; then the next 50 minutes were dedicated to viewing the model. The DAT was administered using the Google Forms platform, with students having 1.20 seconds per question. Figure 5 illustrates the timed development of each phase. Figure 6 presents the evidence from the experiment.

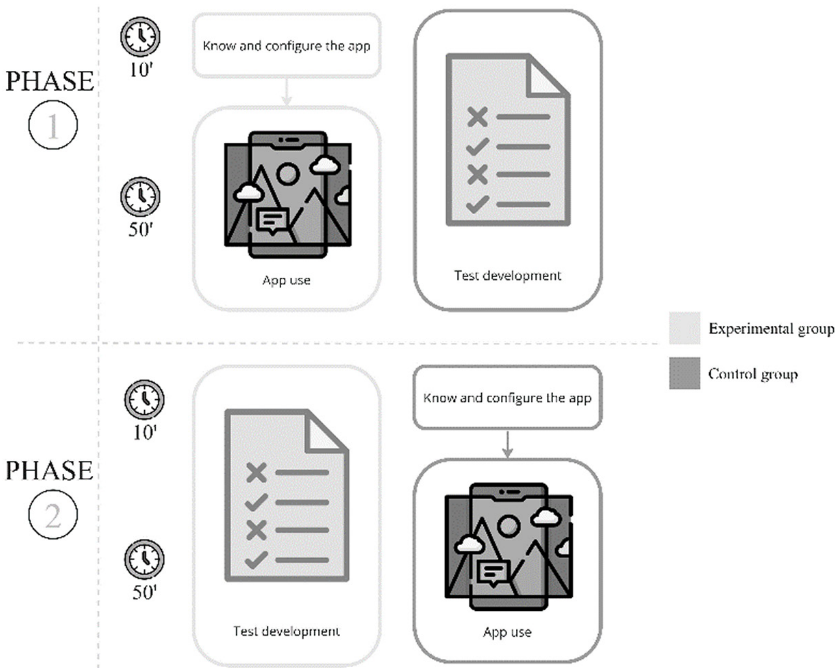

Fig. 5. Timed development by phase

Fig. 6. Evidence from experimentation

Data processing techniques. Following the guidelines provided by Hernández Sampieri et al. [91], the data processing was conducted as illustrated in Figure 7. First, to process the data obtained from the DAT, a spreadsheet was constructed considering the qualitative characteristics of each element in the sample, such as age, section, area of preference, and gender, among others. A table was created within the spreadsheet to calculate the scores obtained by each student for each question. To mechanize the obtained scores, automated functions were used.

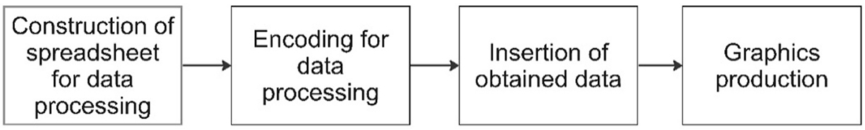

Fig. 7. Flowchart for data processing

4 RESULTS AND DISCUSSION

Figure 8 illustrates the distribution of average scores for both the control group and the experimental group. The experimental group achieved a higher average score compared to the control group. The average scores were 44.9 out of 50 and 30.45 out of 50, respectively. As expected, the experimental group achieved a higher average score than the control group, confirming that the teaching-learning methodology utilizing the VT-Platform AR tool effectively developed and reinforced spatial skills among the students in the experimental group. This is consistent with the studies conducted by Gómez-Tone et al. [28], Roca et al. [30], and Martín-Gutierrez et al. [31], who found that the use of augmented books effectively improved the spatial skills of students from various universities.

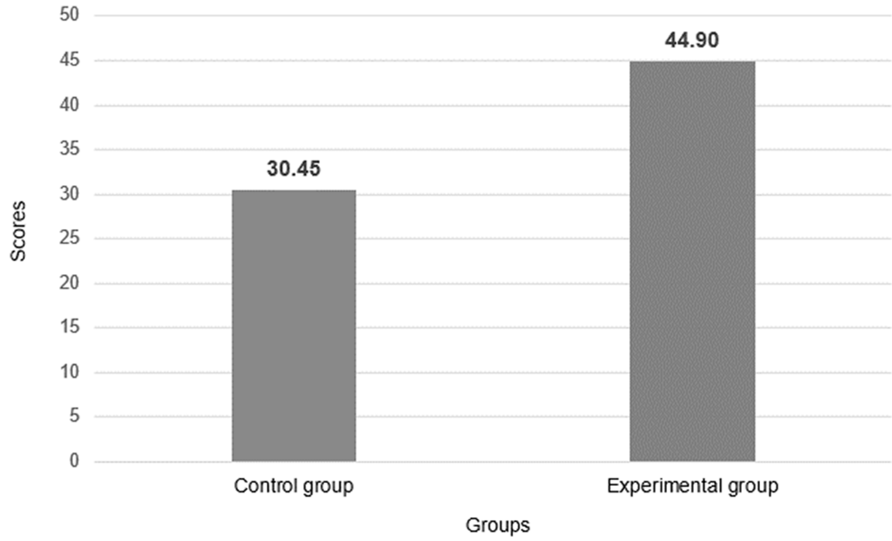

Fig. 8. Average scores by groups

Furthermore, Figure 9 displays the average scores by gender for both the control group and the experimental group. While a similar average score was obtained for the female and male genders within the control group (30.75 and 30.38, respectively), the female participants achieved a higher average score than the male participants within the experimental group (50 and 45, respectively). Linn and Petersen [47] suggest that these differences depend on the tasks that students are asked to perform. Furthermore, according to Peters [96], men can solve exercises more quickly, while women are more cautious and tend to review their answers, which may explain why they have a higher average. The results are similar to those obtained in the study by Gómez et al. [28], who argued that such findings could impact women's interest in pursuing careers in science, technology, engineering, and mathematics (STEM) fields. In fact, Islam [97] argued that both men and women have the necessary attributes to successfully develop careers in STEM. Consequently, more women are pursuing careers in the field of engineering [98].

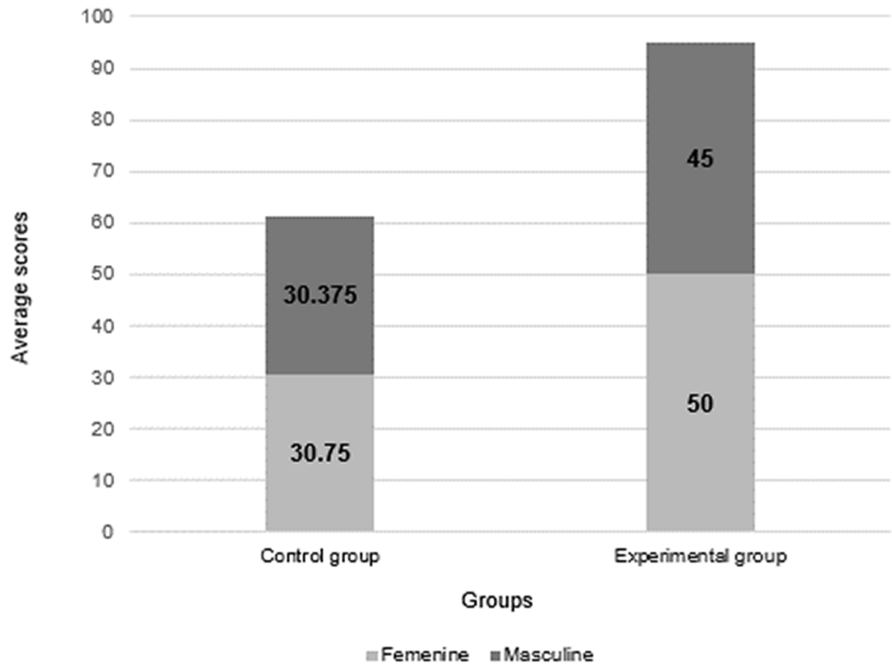

Fig. 9. Average scores by gender for each group

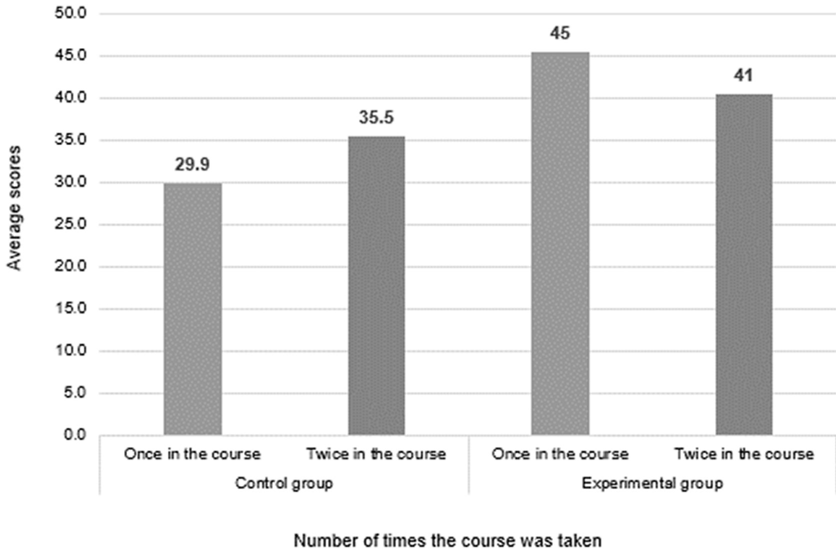

Fig. 10. Average scores according to the number of times the course was taken, by each group

Figure 10 presents the average scores based on the number of times the subject was taken (once or twice) for both the control group and the experimental group. Within the control group, students who took sanitary engineering for the second time obtained a higher average score (35.5) than those who took the subject for the first time (29.9). This situation may be due to the fact that, as Quiroz and Yogui [99] stated, some students are able to change their attitude towards their performance after failing a subject. In contrast, within the experimental group, students who took sanitary engineering for the first time achieved a higher average score (45) than those who took the subject for the second time (41). This may be explained by the presence of demotivation and personal dissatisfaction that is generated after failing a subject more than once, or by having subjects lagging behind [100, 101].

Regarding age, no significant differences were found in the average scores. In fact, age is not a determining factor directly related to spatial skills. Furthermore, according to Gutiérrez et al. [102], these skills reach their maximum level between 14 and 18 years and subsequently decrease slowly. Therefore, the results of this study are consistent with the literature.

With reference to the measures of central tendency and dispersion, Table 4 displays the mean, standard deviation, variance, median, and mode for the control and experimental groups. The standard deviation of the experimental group, 5.95, is lower than that of the control group, 13.87. This suggests that the teaching-learning methodology using the VT-Platform AR tool successfully standardized the level of spatial skills within the group. Gómez et al. [34] and Roca et al. [30] obtained similar results in the standard deviations of their experimental and control groups. Additionally, the median and the mode were higher within the experimental group, indicating that the averages obtained by that group were higher compared to those of the control group and that these higher scores were repeated more frequently.

Table 4. Table of the mean, standard deviation, variance, median and mode for the average variable of the control and experimental groups

Experimental Group	Variable	N	N*	Mean	Standard Deviation	Variance	Median	Mode	N for Mode
Control group	Averages scores	20	0	30.45	13.87	192.47	31.00	14;20;45	2
Experimental group		20	0	44.90	5.95	35.36	48.00	50	6

Note: The asterisk (*) reports the missing values/data.

Table 5 presents the mean, standard deviation, variance, median, and mode by gender for the control and experimental groups. Regarding the standard deviation, the experimental group has a lower value than the control group. This suggests that the teaching-learning methodology utilizing an AR tool successfully standardized the spatial skills of the group. Furthermore, comparing the medians obtained between male and female participants in both the control and experimental groups, it can be observed that the participants in each group exhibited a similar level of visualization ability. Finally, there is no mode for the female participants since only five took part in the study, neither the control group nor the experimental group.

Table 5. Table of the mean, standard deviation, variance, median and mode for the average variable by gender for the control and experimental groups

Experimental Groups	Variable	Gender	N	N*	Mean	Standard Deviation	Variance	Median	Mode	N for Mode
Control group	Average scores	Feminine	4	0	30.75	11.64	135.58	29.50	*	0
		Masculine	16	0	30.38	14.72	216.65	31.00	14;45	2
Experimental group		Feminine	1	0	50.000	*	*	50.000	*	0
		Masculine	19	0	44.63	5.98	35.80	48.00	50	5

Note: The asterisk (*) reports the missing values/data.

5 CONCLUSIONS AND FUTURE WORK

In the present study, a direct and short-term teaching-learning methodology has been proposed to enhance spatial skills, specifically focusing on the spatial visualization component, among a group of undergraduate civil engineering students. The methodology has been based on the use of the VT-Platform AR tool. It was found that the proposed teaching-learning methodology effectively developed and reinforced spatial skills within the experimental group, showing a 29.8% difference compared to the control group. Furthermore, it was concluded that the use of the VT-Platform AR tool helped standardize the level of spatial skills within the experimental group.

It was also observed that women in the sample within the experimental group obtained scored 10% higher than men. In the present scenario, an increasing number of women are opting for STEM careers. It has been demonstrated that both men and women possess the essential attributes required to excel in this field. Additionally, the methodology indirectly revealed the performance of students who were retaking the subject, with higher averages observed in the control group and lower averages in the experimental group. Finally, the teacher who conducted the experiment observed that the students were able to work autonomously, and in general, it was not necessary to assist them during the training process. This suggests the benefits and pedagogical advantages of AR, which is easy to use. Therefore, it is highly recommended to use AR tools for the teaching and learning processes within the engineering field.

As for future works, it is recommended to apply the teaching-learning methodology using the VT-Platform AR tool or similar tools across various thematic teaching-learning units in additional civil engineering subjects. This approach aims to enhance the monitoring of each student's training process evolution. Studies with larger samples in the field of sanitary engineering are also recommended to enhance the external validity of the results and facilitate broader generalization to other higher education institutions. Furthermore, this research topic could be expanded to other AECO specialties, including architecture.

Finally, it would be valuable to study the causes of the differences in spatial skill levels among civil engineering students and investigate how training with AR could impact the different subjects within the civil engineering curriculum.

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7 DECLARATION OF INTEREST STATEMENT

No potential conflict of interest was reported by the authors.

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