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RESEARCH ARTICLE

The Experience of Using a New e-Learning Tool in Architectural Studies

PAU XIBERTA[1], SANTIAGO THIÓ-HENESTROSA[2], JOAN FONTÀS[3], AND IMMA BOADA[1]
[1]Graphics and Imaging Laboratory, Universitat de Girona, Girona, 17003 Catalonia, Spain
[2]Departament d'Informàtica, Matemàtica Aplicada i Estadística, Universitat de Girona, Girona, 17003 Catalonia, Spain
[3]Departament d'Arquitectura i Enginyeria de la Construcció, Àrea de Construccions Arquitectòniques, Universitat de Girona, Girona, 17003 Catalonia, Spain

Corresponding author: Pau Xiberta (pau.xiberta@udg.edu)

This work involved human subjects or animals in its research. The authors confirm that all human/animal subject research procedures and protocols are exempt from review board approval.

ABSTRACT The COVID-19 pandemic has accelerated the use of e-Learning technologies as an alternative to classical face-to-face teaching. Teachers have had to quickly adapt to virtual technologies and transform their material to online content in order to minimise the impact on students' education. In studies such as Architecture, where visual and graphical representations are fundamental, such an adaptation is challenging. The aim of this paper is to evaluate a new e-learning methodology in architectural studies by using SAPIENS, a specifically designed e-learning platform with content creation tools and automatic correction. This platform was used to create an e-learning course on building systems. To evaluate and measure the effectiveness and acceptance of the proposed methodology in architectural education, an experiment with 108 students was carried out. Participants were divided into two homogeneous groups, *G1* and *G2*, and only *G1* was given access to the e-learning platform to take the course. The results were obtained by means of pre- and posttesting and a questionnaire. Significant differences were found between pre- and posttest scores, and nearly significant differences were found between the posttest scores of *G1* and *G2*. The mean of all questionnaire scores exceeded 3.5 on a five-point Likert scale except for one question. *G1* rated better overall, and there were no significant differences by age, degree, subject or e-learning experience. Teacher's opinion was very satisfactory as well. Therefore, the proposed methodology, with high image interaction and adapted to all participant profiles, helps in the process of learning and is highly accepted by learners, specially those who are engaged.

INDEX TERMS Architecture, content creation, COVID-19 pandemic, e-Learning, feedback, image-based learning, visuospatial skills.

I. INTRODUCTION

The COVID-19 pandemic has led to different changes in education with an impact not only on students but also on teachers [1], [2]. The imposed social distancing measures reduced face-to-face sessions, being replaced by new working methodologies where remote classes and virtual meetings became essential. Assessment methodologies were also modified to accommodate the newly imposed restrictions. From the teaching point of view, instructors had to quickly adapt to virtual technologies and transform their materials into online content in order to minimise the impact on students' education [3], [4]. While technology and e-learning tools are undoubtedly key elements of education systems, not all teachers are as familiar with them as it would be desired [5], [6]. Generally, in non-distance studies, e-learning tools are only used in some parts of the courses, and the process of adapting all the content to a virtual channel requires an extra effort by

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the teacher [7]. An effort that was even harder in the pandemic situation, where a rapid response was required [8]. It is in these circumstances where the experience of using a new e-learning methodology in the context of the architectural studies is presented.

E-learning focuses on the use of computer and network technologies to enhance teaching and learning, while preserving or improving the interactivity of face-to-face learning. Advances in technology and the reduction in the cost of electronic equipment have made it possible to conduct classes remotely through the use of different devices. This concept is developed by the recent field of mobile learning (or m-learning), which can be defined as learning across multiple contexts, through social and content interactions, using personal electronic devices [9]. With the possibility of using personal mobile devices as learning tools, this model has become an attractive trend that has led many researchers to examine its acceptance by learners and instructors [10]. Consequently, over the last few years e-learning has gained great importance at all educational levels, from primary school to universities [11], [12], [13], and also in the context of architectural studies [14], [15]. However, the nature of these studies requires special attention, as concepts such as planning, designing, modelling and overseeing a building's construction require graphical representations which add a level of complexity to the design of e-learning tools. The fact is that visuospatial thinking theories play a decisive role in these studies, since learner's understanding can be improved if they are properly used during the learning process [16], [17], [18]. In this regard, different technology-based strategies have been proposed to put theoretical concepts into practice, and also to enhance learners' motivation and acquisition of knowledge. Building Information Modelling (BIM), which represents a transition from 2D to 3D drawings in architectural design, is introduced in most schools to adequately prepare students for their entry into the industry [19], [20], [21], [22], [23]. BIM is actively used in the Architecture, Engineering and Construction industries, where coordination between multidisciplinary teams is required. It covers nearly the whole process of a project, including design, 3D modelling, scheduling, resource management, construction and maintenance. In addition, its models provide a 3D visualisation of the building, making it easier for cross-discipline professional engineers and other project participants to demonstrate their design intent [24].

Virtual reality (VR), which has been explored for years [25], is increasing its use in learning environments due to its benefits compared to classical education [26], [27], [28]. In the area of architecture, VR allows the exploration and manipulation of 3D interactive environments in real time, providing advantages such as representational fidelity, the feeling of presence or immersion, and immediate control over the scenes with the ability to look at objects from different points of view and manipulate them [29]. This technique facilitates the design, engineering, construction and management for the built environment [30]. Recently, Zhang and Chen [31] proposed a VR-based learning and teaching method for architectural engineering students. Their method supports different design scenarios, so that design theories and schemes can be thoroughly understood and investigated. Moreover, students can investigate, amongst other things, how a building is built and what safety issues should be considered on site. Davila Delgado *et al.* [32] evaluated the state of the art in VR in the construction industry, and they also highlighted the findings that are relevant to both academia and industry. They concluded that there is a high interest in VR even though existing technologies are not capable of meeting current demands, this being an open area of research. The simultaneous use of BIM and VR has also been proposed to improve workspace planning related to construction activities and the sharing of safety-related information [33], [34], [35].

Different studies such as those that have been cited have proved the effectiveness of integrating these tools into the curriculum of architectural studies. However, these studies have focused on students, and little importance has been given to teachers. Generally, all the aforementioned strategies require a content creation process to provide students with material related to the topic to be taught. Teachers must not only spend time preparing this material, they should also be highly innovative and confident to use these new technologies. Besides, it must be taken into account that graphical/visual representations are a key part of the content, and dealing with them increases the complexity of the content creation process. Therefore, the challenge is how to simplify or automate this content creation process as well as the related correction strategy in order to facilitate the teacher's job and keep track of the student's progress by exploiting the advantages of e-learning tools. To tackle this problem, an e-learning platform has been designed where student needs are as important as those of the teacher. In the first version of the platform, the interest has been focused on how to reduce the complexity of content creation in exercises where interaction with 2D graphical representations is required.

The aim of this paper is to evaluate a new e-learning methodology in architectural studies by using this e-learning platform called SAPIENS (System with Authoring tools to Practise in Image-based ENvironments for Simulation). SAPIENS provides: (i) an authoring environment for architecture teachers to prepare exercises where graphical content and students' interaction are fundamental; (ii) a set of strategies that automatically correct students' solutions; (iii) a learning environment where students can solve exercises and get immediate feedback. The hypothesis of the study is two-fold: (i) the use of the proposed interactive methodology improves learning and the results do not worsen compared to the classical methodology, and (ii) the proposed methodology is engaging for students. In this regard, the tool and the methodology are evaluated to measure their effectiveness and acceptance in architectural engineering education. The study also considers whether the m-learning approach is interesting for students by paying special attention to one of the questions provided to assess the acceptance of the proposed methodology.

II. MATERIAL AND METHODS

A. THE SAPIENS PLATFORM

SAPIENS is a web-based, cross-browser and multilingual e-learning platform that has been conceived to prepare teaching and learning material with three core ideas: image interaction should play the main role, content creation should be as effortless as possible, and exercises should be corrected automatically. Thus, the platform has been designed considering exercises as the key element of the entire learning process.

1) COURSE STRUCTURE

The SAPIENS platform allows the creation of several courses. Each course is divided into different topics, and each topic can contain theoretical content or exercises. The design is exercise-based, so that the theoretical content is considered as supplemental material. For each topic, the theoretical content is divided into theory pages, each of which consists of an interactive image and a related rich text. This content is always available from the course's main page and from each of the topic's exercises. As for the exercises, they are associated with a topic, and they may require the student to perform different actions to solve them. However, they always include an image with which the students can interact. Although some exercise types support a higher interaction level, an interactive image can always be zoomed in and panned. Feedback may be given before the exercise is solved by means of the tip button, and after it is solved by displaying a message and indicating whether the answer is correct. The platform provides functionalities to control learners' work and visualise their progress with respect to other learners of the course.

2) EDITORS

Specific editors are provided for teachers to create theory material and exercises. Regarding theory pages, the editor is simple and allows teachers to upload images and write rich text (HTML text). Nonetheless, there are several types of exercises and, although they share a common structure, they may require different information. Generally, the structure of the exercise editors is based on the main actions taken by teachers when preparing an exercise. This pipeline can be summarised as: (i) selecting an image to be studied, (ii) defining the question related to the image, (iii) waiting for the student's answer, and (iv) correcting the answer and giving feedback to the student. Following these steps, each exercise is created using a general template. First, the teacher selects and uploads the image related to the exercise. Second, the question is formulated in the corresponding text box. Third, the teacher decides the feedback to be given and whether help messages have to be provided. Finally, specific information is required for the platform to automatically correct the exercise, where several situations are considered according to the exercise type. Amongst the available exercise types, there are multiple-choice questions and identification of image regions, either by selecting points on the image or by drawing polylines, i.e. connected series of line segments (polygonal chains). The platform provides other more specific exercise types that will not be used in this study.

To use the editors, no special knowledge is required other than basic notions of text editors. To make the content creation process simpler, the editor adapts to the solution required for the selected exercise type. For instance, if the exercise is a multiple-choice question, the teacher has to select the correct solution by using check boxes; if the exercise requires the selection of points or drawing polylines on the image, the teacher has to use the provided tools to mark out the correct area. These tools take the shape of the region into account: if a circular region is selected, the teacher is able to increase or reduce the radius; if a polygonal area is selected, the teacher is able to change the colour and radius of each vertex, the colour, thickness and curvature of the outline, and the colour and opacity of the fill colour. The teacher can also add, edit or remove points from a polygonal area. All configuration parameters are set by default, and teachers only have to adjust them according to their preferences. See Fig. 1 for an example of the editor interface.

3) AUTOMATIC CORRECTION

Besides simplifying the content creation process, one of the most relevant features to reduce teachers' effort is the automatic correction of the exercises. To automatically correct students' answers, a different strategy must be adopted for each exercise type. Hence, the corresponding exercise editor asks for different parameters depending on this strategy. Although the platform supports several exercise types, in the present study only two of them have been employed:

- **Region identification by selecting points.** These exercises present a 2D image over which the student has to mark one or more points of interest. To determine these points, the system allows the teacher to add regions over the image. The exercise editor provides functionalities to drag and move regions that have already been added, and to edit or remove them as well. The correction strategy checks whether the points selected by the student lie inside the corresponding regions indicated by the teacher, in which case the answer is considered correct. On this occasion, the teacher decided that for an answer to be correct each point has to correspond to exactly one region (incorrect otherwise).
- **Region identification by drawing polylines.** These exercises present a 2D image over which the student has to draw one or more polylines. To determine these polylines, the system provides the teacher with the same functionalities described before, which allow the creation and editing of regions over the image. The correction strategy checks whether the area of the student-drawn regions overlaps enough with the area

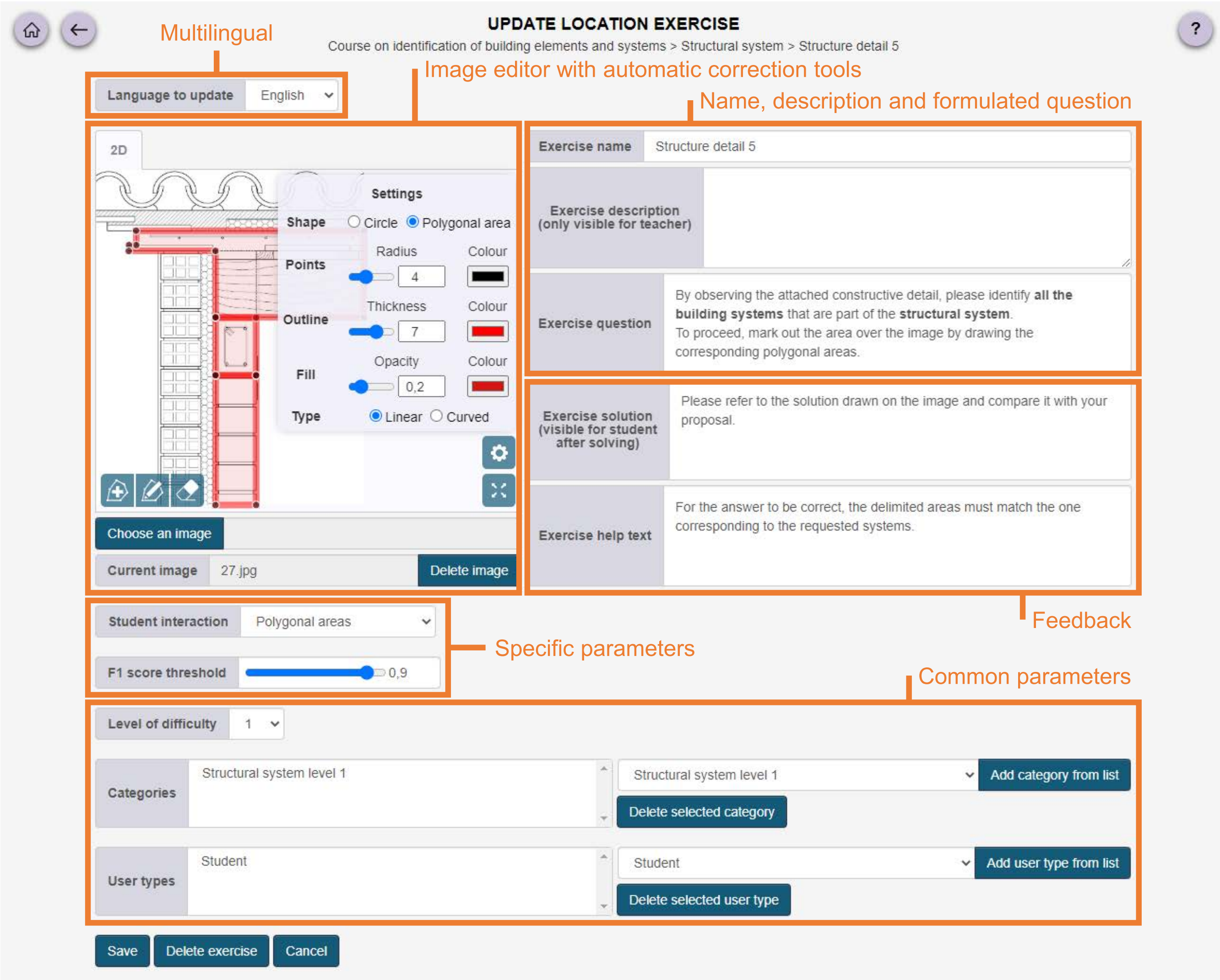

FIGURE 1. Elements of the exercise editor interface (example corresponding to a region identification exercise where students have to draw polylines).

of the teacher-drawn ones, in which case the answer is considered correct. To calculate the overlap, the F-score measure is used [36], [37], whose result can be interpreted as a measure of the overlap between two regions. To discern whether the overlap is enough, a threshold for the F-score measure is set by the teacher in the exercise editor.

B. A COURSE ON BUILDING SYSTEMS

The online material was prepared by an architect with more than 25 years of experience in teaching. As a starting point, he took his own presentation slides and constructive details used in his face-to-face classes. By using the editors integrated into the SAPIENS platform, he was able to easily translate these documents into online contents, be it theoretical content or related exercises. Hence, he was not forced to prepare the material from scratch. The same editors allowed him to assign help messages and feedback to the exercises to guide the learners through the learning process. As shown in Table 1, the main course was organised in 13 topics, most of which have related exercises (50 in total).

For the creation of the exercises, the teacher used two different strategies, which correspond to the types of exercises described in the previous section. Given a constructive detail, the first strategy that he followed lies in asking the student to mark points over the image where the building elements are supposed to be. As long as the student selects points within the teacher-drawn regions (corresponding to the actual building elements), the answer will be considered correct. As for the second strategy, the teacher asks the student to draw regions over the constructive detail to delimit the existing building systems. For an answer to be considered correct, the student-drawn regions have to sufficiently overlap with the actual building systems drawn by the teacher. In Fig. 2, some screenshots of the platform from the student point of view are illustrated.

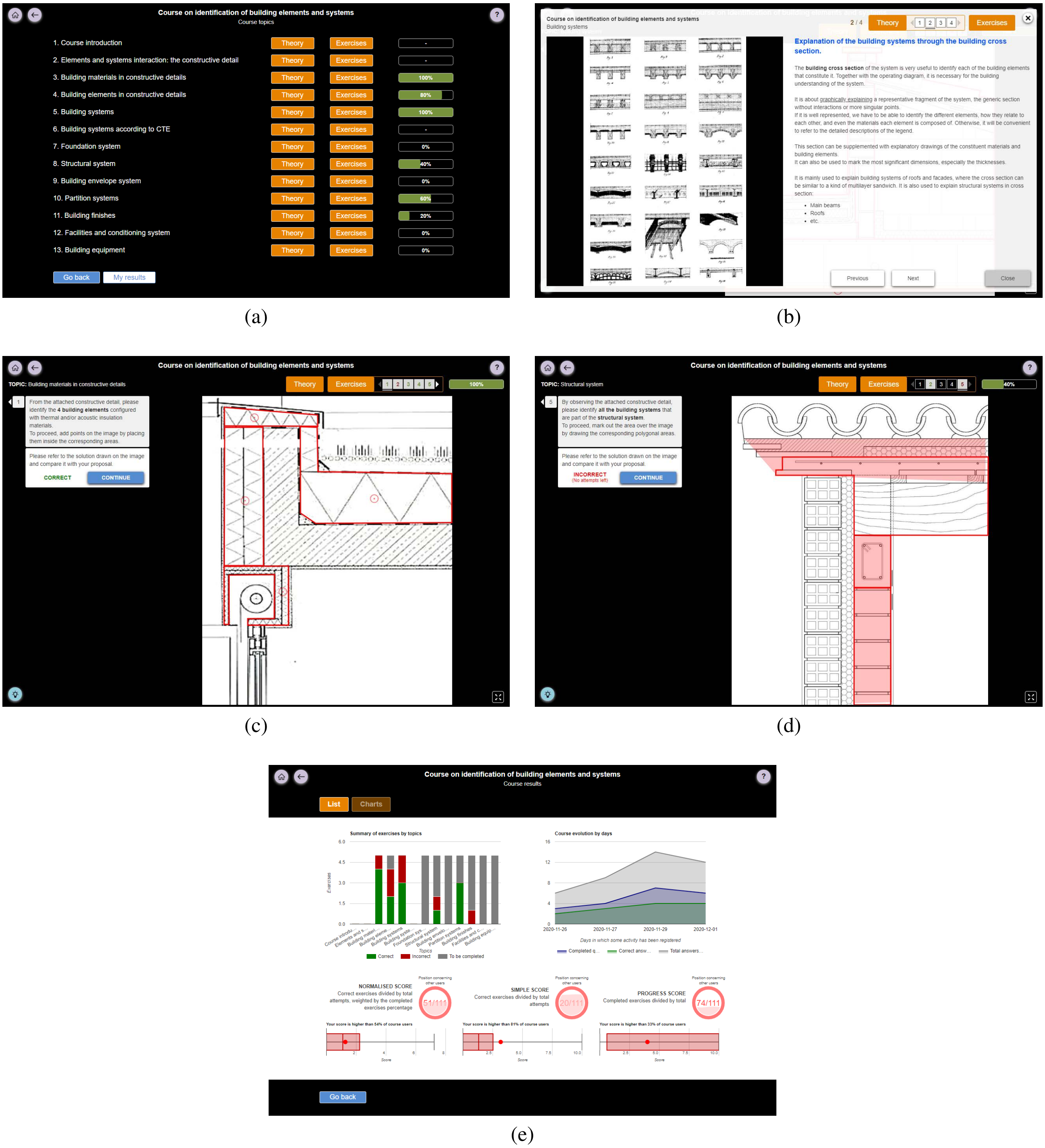

FIGURE 2. **Screenshots of the platform from the student point of view: (a) Course contents with the topics, the buttons to access theory and exercises, and the progress bar indicating the percentage of exercises that have been solved; (b) A theory page with the buttons to navigate to other pages and access the related exercises; (c) An example of a correctly solved exercise where learners have to identify regions by selecting points; (d) An example of an incorrectly solved exercise where learners have to identify regions by drawing polylines; and (e) Some statistics of learner progress such as number of exercises solved per day, number of correct exercises per topic, and position of the participant with respect to other members of the course.**

C. PARTICIPANTS

The participants involved in this study are 108 students enrolled in architecture degrees. They come from two different bachelor's degrees, namely the five-year bachelor's degree in Architectural Studies (BARCH) and the four-year bachelor's degree in Architectural Technology and Building Construction (BATBC). They also come from three different subjects, namely Building technology 2 (BT2), Building

TABLE 1. Topics of the course on building systems.

Topic	Theory pages	Exercises
Course introduction	1	-
Elements and systems interaction: the constructive detail	1	-
Building materials in constructive details	2	5
Building elements in constructive details	2	5
Building systems	4	5
Building systems according to CTE	1	-
Foundation system	1	5
Structural system	1	5
Building envelope system	1	5
Partition systems	1	5
Building finishes	1	5
Facilities and conditioning system	1	5
Building equipment	1	5

technology 3 (BT3) and Analysis of the construction process (ACP). Their age ranges from 19 to 36 years old, and there are students from up to four different examination sittings. All participants consented to be included in the study, and the experiment in which they have participated has been conducted according to the Declaration of Helsinki principles.

D. EXPERIMENTAL DESIGN

To analyse the results and the acceptance of the proposed e-learning methodology, thus testing the hypothesis studied, a stratified sampling approach is used to divide the participants into two homogeneous groups. The composition of each group is made by means of a random sample within each of the strata. In other words, the participants are divided into two groups so that each one has a similar ratio of each of the available categories: examination sitting, bachelor's degree, age, gender and subject. The purpose of the experiment is to implement two different learning approaches and evaluate the differences in the results. Accordingly, the first group (*G1*) carried out the whole learning process using the proposed e-learning platform, while the second one (*G2*) underwent a hybrid experience.

Aside from the course, the teacher used the proposed e-learning platform to prepare a test. This test comprises 20 exercises ordered by difficulty (from lowest to highest) and, although they are somehow similar, the exercises of the test are different from those of the course. The test, together with the course, is used to evaluate the results of both learning approaches by means of a pre- and posttest evaluation. The procedure that was followed is depicted in Fig. 3 and described below:

1) *G1* and *G2* carry out the test (*T1*) as a pretest, with a single attempt per exercise, and with no feedback, i.e. the students do not know the solution after solving.
2) *G1* carries out the course using the proposed e-learning platform, with three attempts per exercise, and with feedback, i.e. the solution is displayed when the student correctly solves the exercise or when there are no attempts left.

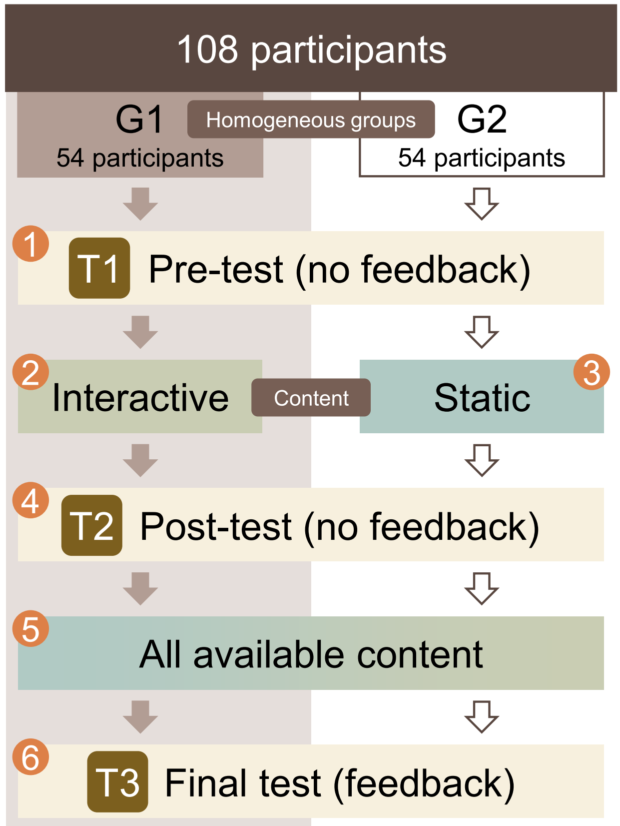

FIGURE 3. Diagram of the learning process followed by each group of participants (*G1* and *G2*).

3) At the same time, *G2* is given access only to the theory material in the form of a text document with images, but with no interaction with the e-learning platform.
4) *G1* and *G2* carry out the test again (*T2*) under the same conditions, i.e. a single attempt per exercise and no feedback, but now as a posttest after the learning process.
5) To balance the opportunities for each student, *G1* and *G2* are given access to the whole available material, so *G2* can now access the course and carry it out using the e-learning platform.
6) *G1* and *G2* carry out the test for the last time (*T3*), but now with three attempts per exercise and feedback, so that they can know the solution to the exercises.

After completing 80 % of the course, all participants had the opportunity to fill in the questionnaire presented in Table 2. To answer some questions, the Likert scale (1 = total disagreement, to 5 = total agreement) was used [38]. To test the reliability of the questionnaire, Cronbach's alpha was checked, and to validate it, a confirmatory factor analysis was performed.

E. STATISTICAL ANALYSIS

To analyse whether the participants improved their knowledge throughout the experiment, the means of the

TABLE 2. Participant questionnaire to evaluate the proposed methodology.

GENERAL INFORMATION
How many online courses have you participated in, aside from this one? [0, 1 to 3, > 3] Do you think that an optimised version of this platform for smartphones would be useful? [Yes, No]
GLOBAL EVALUATION (1 = Totally disagree, to 5 = Totally agree)
(Q01) Globally, I favourably evaluate the course (Q02) I would recommend this teaching methodology to my teammates
USABILITY (1 = Totally disagree, to 5 = Totally agree)
(Q03) It was easy for me to interact with images (Q04) It was easy for me to access and navigate through the content pages (Q05) It was easy for me to access and navigate through the exercises (Q06) It was easy for me to identify each icon with its function
CONTENTS (1 = Totally disagree, to 5 = Totally agree)
(Q07) The topics in which the course was structured are appropriate (Q08) The course contents met my expectations (Q09) The balance between exercises and content was appropriate (Q10) Participating in this activity will allow me to improve elements of my daily work
OPEN QUESTIONS
Aspects that you would suggest to improve this teaching methodology Positive aspects of this teaching methodology that you would emphasise Topics or issues on which I would like to take a course

pre- and posttest scores are compared by means of a paired t-test. When the analysis concerns the ability of the e-learning methodology to increase the participant's knowledge, an unpaired t-test is carried out to compare the scores of each group.

Regarding the evaluation of the methodology's acceptance, some analyses are performed to compare the results by some of the available characteristics. Age is transformed to a 2-categorical variable (less than 24 years old, and more than or equal to 24), similarly to the examination sitting (separating the first from the subsequent ones). The number of online courses previously attended, i.e. the e-learning experience, is transformed to a 3-categorical variable: none (0), few (1 to 3) and many (more than 3). Depending on the number of categories of independent variables, Mann-Whitney U test (two categories) and Kruskal-Wallis test (more than two categories) are used to find significant differences by group, age, bachelor's degree, subject, e-learning experience and interest in a smartphone version of the platform.

III. RESULTS

A. PARTICIPANT PROFILES

The experiment was performed by 108 students who, despite sharing the study of a common topic, i.e. building systems, have different characteristics. To divide the students into two similar groups, these characteristics have to be homogeneously distributed. Table 3 shows, for each group, the number and percentage of participants in each category. Note that the last two characteristics are not taken into account in this distribution, as this information has been gathered after the experiment.

Table 3 shows not only the distribution of characteristics for each group, but also the total amount of participants in each category. Almost all of the students come from BARCH, and most of them are in the first examination sitting and are less than 24 years old. Regarding gender and subject, percentages are similar. Moreover, few students have experience in this kind of courses (almost two thirds have never attended an online course before), and approximately two thirds are interested in a smartphone version of the platform. Therefore, the average profile is a BARCH student, in the first examination sitting, less than 24 years old, with little or no experience in online courses, and interested in the smartphone version. The last two characteristics have a different total number of participants, since not all the students filled in the questionnaire where this information was required (or did not provide this information in particular).

B. TEST RESULTS

Once the experiment was carried out, the results were analysed by comparing the scores between the pretest and the posttest, which comprise the same 20 exercises. A participant's score in a test corresponds to the number of correctly solved exercises.

As shown in Table 4, the scores between the pretest and the posttest are significantly different (p-value < 0.05), no matter which group is analysed. Therefore, all students increase their knowledge in the learning process. As there is a relationship between the two samples, a paired test is performed to evaluate the differences, so that only those participants who answered both tests are taken into account.

If the scores are analysed between groups and for each test, the results differ (see Table 4). Regarding the pretest, although

TABLE 3. Characteristics of participants.

		Number of participants (%)		
		G1	*G2*	Total
Examination sitting	First	47 (87.04 %)	46 (85.19 %)	93 (86.11 %)
	Subsequent	7 (12.96 %)	8 (14.81 %)	15 (13.89 %)
Bachelor's degree	BARCH	50 (92.59 %)	50 (92.59 %)	100 (92.59 %)
	BATBC	4 (7.41 %)	4 (7.41 %)	8 (7.41 %)
Age	< 24	47 (87.04 %)	45 (83.33 %)	92 (85.19 %)
	≥ 24	7 (12.96 %)	9 (16.67 %)	16 (14.81 %)
Gender	Female	23 (42.59 %)	22 (40.74 %)	45 (41.67 %)
	Male	31 (57.41 %)	32 (59.26 %)	63 (58.33 %)
Subject	BT2	21 (38.89 %)	21 (38.89 %)	42 (38.89 %)
	BT3	16 (29.63 %)	19 (35.19 %)	35 (32.41 %)
	ACP	17 (31.48 %)	14 (25.93 %)	31 (28.70 %)
Online courses	None	20 (66.67 %)	12 (57.14 %)	32 (62.75 %)
	Few (1 to 3)	8 (26.67 %)	4 (19.05 %)	12 (23.53 %)
	Many (> 3)	2 (6.67 %)	5 (23.81 %)	7 (13.73 %)
Smartphone version	Yes	22 (70.97 %)	12 (57.14 %)	34 (65.38 %)
	No	9 (29.03 %)	9 (42.86 %)	18 (34.62 %)

TABLE 4. Differences in the scores for each group between the pretest and the posttest, and differences in the scores for each test between *G1* and *G2*, with p-values.

					Percentiles						
		mean	sd*	IQR*	0 %	25 %	50 %	75 %	100 %	n*	p-value
G1	Pretest	2.17	1.77	2	0	1	2	3	6	48	**< 0.0001**
	Posttest	5.02	2.94	5	0	3	5	8	11	48	
G2	Pretest	2.35	2.07	2.25	0	1	2	3.25	8	48	**< 0.0001**
	Posttest	4.06	2.96	5	0	1	3	6	10	48	
Pretest	*G1*	2.06	1.74	2	0	1	2	3	6	52	0.4854
	G2	2.32	2.03	2	0	1	2	3	8	50	
Posttest	*G1*	5.02	2.94	5	0	3	5	8	11	48	0.0661
	G2	3.92	2.94	5	0	1	3	6	10	51	

*sd = standard deviation, IQR = interquartile range, n = number of participants, bold values indicate significant differences

G2 has a higher average score, no significant differences are observed. However, when it comes to the posttest, the average score of *G1* exceeds that of *G2*, with nearly significant differences. Hence, the knowledge of the students can be considered the same before the learning process, but possibly higher for *G1* students afterwards. As there is no relationship between the two samples, an unpaired test is performed to evaluate the differences, so that each test takes into account the participants who answered it; thus, the number of participants for each group may differ.

C. QUESTIONNAIRE RESULTS

1) RELIABILITY

The internal consistency reliability of the scale, as indicated by the Cronbach's alpha coefficient of 0.85, is quite satisfactory and is in an acceptable range for educational and psychological tests suggested by professional testing organisations [39].

2) VALIDITY

The confirmatory factor analysis confirms quite well the classification of the questions described in Table 2 (Global Evaluation, Usability and Contents). Table 5 and Figure 4 show the results of this analysis.

Questions included in the Global Evaluation block (Q01 and Q02) are highly correlated ($r \geq 0.87$) with the F3 factor.

Questions included in the Contents block (Q07 to Q10) are moderately correlated ($r \geq 0.63$) with the F1 factor except for Q10 (''Participating in this activity will allow me to improve elements of my daily work''), which is associated with the previous factor (F3) with a moderate correlation ($r = 0.62$). This is not unusual, as this question, with its wording, could easily fit into the Global Evaluation block.

Finally, of questions included in the Usability block (Q03 to Q06), only two (Q04 and Q05) are associated with the same factor (F2) with high correlation ($r \geq 0.73$). Q06 (''It was easy for me to identify each icon with its function'')

TABLE 5. Standardised loadings (pattern matrix) based upon correlation matrix in factor analysis.

	F3	F1	F2	h^{2*}	u^{2*}	com*
Q01	**0.97**	0.06	0.10	0.96	0.041	1.0
Q02	**0.87**	0.21	-0.01	0.79	0.205	1.1
Q03	**0.38**	**0.38**	0.07	0.30	0.704	2.1
Q04	-0.01	0.17	**0.94**	0.92	0.081	1.1
Q05	0.18	0.35	**0.73**	0.69	0.313	1.6
Q06	0.05	**0.53**	0.16	0.31	0.689	1.2
Q07	0.22	**0.63**	0.39	0.60	0.398	1.9
Q08	0.47	**0.64**	0.06	0.63	0.371	1.9
Q09	0.15	**0.69**	0.21	0.54	0.459	1.3
Q10	**0.62**	0.43	0.23	0.63	0.371	2.1

*h^2 = communality, u^2 = uniqueness, com = item complexity

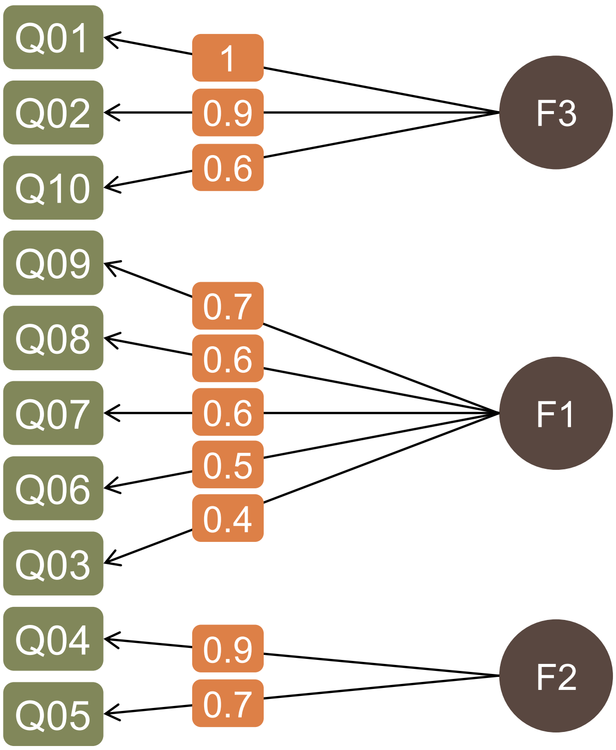

FIGURE 4. Path diagram of the confirmatory factor analysis.

is associated with the Contents block, but the correlation is only 0.53. As for Q03 (“It was easy for me to interact with images”), it has a very poor correlation with all factors ($r = 0.38$ for F1 and F3). As all exercises involved image interaction, participants chose this question to reflect the difficulty of the exercises.

Unfortunately, we only have 52 complete questionnaire responses to evaluate the proposed methodology, and with this sample size, the reliability and theoretical soundness of the solutions should be assessed very carefully [40].

3) ANALYSIS

Although only *G1* participants had access to the online course to train for the posttest, *G2* participants were given access to it after the experiment too. The online course included the option to fill in the questionnaire presented in Table 2, which serves the purpose of evaluating the acceptance of the e-learning methodology. Therefore, not only the test scores are analysed, but also the scores for each of the survey’s questions. The survey is voluntary, so only those participants who answered it are considered. In a similar way, each of the answers can be left blank, so that the sample size can fluctuate depending on the question to be analysed.

Table 6 reveals that the scores of all questions of the survey, except Q03, are greater than 3.5 on a five-point Likert scale, while the median is greater than or equal to 4 (again with the exception of Q03). The scores are also compared for each of the analysed characteristics to look for some relevant differences. A summary of this analysis is represented in Table 7, where significant differences between the scores are found when comparing by group and by the interest in a smartphone version of the platform (p-value < 0.05).

A closer look at the comparison by group (see Table 8) shows that Q01 presents significant differences. The first question is particularly relevant since it corresponds to the global evaluation of the course. Therefore, *G1* globally evaluates the course more favourably than *G2*. However, almost all the other questions are better evaluated by *G2*, being Q07, which presents significant differences, the most representative example.

As for the age, the bachelor’s degree and the subject, no significant differences are found between the scores. Similarly, when comparing by the examination sitting, there are no significant differences either. However, as shown in Table 9, in this last case there is a little trend for the repeat students to rate lower, particularly in Q01.

Finally, there are no differences between the scores when comparing by the experience in online courses, since both the experienced and inexperienced ones scored similarly, but there are clearly significant differences when comparing by the interest in a smartphone version of the platform. Table 10 shows that the scores for Q01 and Q02 (global questions), and also Q10, are significantly different depending on the interest in the smartphone version.

Regarding the open questions in the last block of the questionnaire, the answers of the participants are summarised in three groups:

TABLE 6. Scores for each question of the questionnaire.

	mean	sd*	IQR*	Percentiles 0 %	25 %	50 %	75 %	100 %	n*
Q01	3.7	1.0	1	1	3	4	4	5	52
Q02	3.6	1.1	1	1	3	4	4	5	52
Q03	3.1	1.1	2	1	2	3	4	5	54
Q04	4.5	0.9	1	1	4	5	5	5	54
Q05	4.4	1.0	1	1	4	5	5	5	54
Q06	4.0	1.1	2	1	3	4	5	5	54
Q07	4.4	0.6	1	3	4	4	5	5	54
Q08	3.9	1.0	2	1	3	4	5	5	54
Q09	3.8	0.9	1	2	3	4	4	5	54
Q10	3.9	1.1	2	1	3	4	5	5	54

*sd = standard deviation, IQR = interquartile range, n = number of participants

TABLE 7. Summary of the p-values obtained from the analysis of the differences in the questionnaire scores for each of the relevant characteristics.

	Group	Age	Degree	Subject	Sitting	Online[a]	Smartphone[b]
Q01	**0.0374**	0.8781	0.2207	0.8158	0.0785	0.7689	**0.0117**
Q02	0.2111	0.7570	0.6966	0.6153	0.1449	0.5732	**0.0022**
Q03	0.6750	0.2251	0.1252	0.2837	0.7217	0.7279	0.7953
Q04	0.3466	0.1669	0.9477	0.1867	0.1189	0.3828	0.8846
Q05	0.4366	0.8896	0.6820	0.7345	0.4082	0.4983	0.9911
Q06	0.5759	0.3714	0.5761	0.2262	0.6725	0.9323	0.9675
Q07	**0.0091**	0.1516	0.6476	0.5408	0.8189	0.2046	0.3232
Q08	0.5719	0.0869	0.9406	0.4440	0.4777	0.2704	0.2082
Q09	0.2188	0.1853	0.7852	0.7934	0.3742	0.4699	0.7286
Q10	0.5054	0.1065	0.1402	0.1249	0.3045	0.0767	**0.0211**

[a]Number of online courses previously attended (e-learning experience)
[b]Interest in a smartphone version of the platform
*Bold values indicate significant differences

1) *Aspects that they would suggest to improve the teaching methodology*. The main issue the participants complained about is that the margin of error for the region-drawing exercises is too low. On the exercises, they also remarked that some questions are too broad and poorly defined, that they would like to always know the number of regions to draw, and that there are too many exercises and it turns out to be rather annoying when they have to be repeated. Still related to the content, they said that some images could be more suitable, that some details lack definition, and that the use of different images could avoid the monotony. Finally, regarding usability, they suggested improving the region-drawing tools, allowing for example predefined shapes such as rectangles, or making the edition and removing of polylines easier.
2) *Positive aspects of the teaching methodology that they would emphasise*. The most highlighted aspect is that it is a good methodology which helps in the process of learning. They added that it is a decidedly good way to learn by practising, and that the methodology is very visual, educational, funny, entertaining, interactive, quick and dynamic. They also clearly stated the value of the immediate feedback, which is fundamental to take advantage of errors. As for the content, they valued the use of real images, and they said it is clear and not tedious, well organised, with a good proportion of exercises per topic and a satisfactory relationship between theory and exercises, and that it perfectly complements the contents of the subject. As for usability, they mainly underlined the ease of use, and also the comfort of browsing the platform, the accuracy, and the intuitive design.
3) *Topics or issues on which they would like to take a course*. Participants suggested the option to identify elements on pictures instead of details, to work on real construction pictures, and to take courses on the building process, the actions that are performed in the construction, and different constructive solutions of building finishes and partition systems.

IV. DISCUSSION

Education methodologies were clearly affected by the appearance of the COVID-19 pandemic. This sudden change in the curriculum has led to a forced increment of e-learning tools in all kind of subjects, and architectural studies have not been an exception. To a certain extent, this shock could be seen as a good opportunity to drive the use of new technologies to the architectural curriculum, such as the development of BIM processes or the advantages of virtual reality for a better understanding of the models. Indeed, 3D representations, along with 2D blueprints and drawings, can notably improve

TABLE 8. Questionnaire scores by group, with p-values.

		mean	sd*	IQR*	Percentiles 0 %	25 %	50 %	75 %	100 %	n*	p-value
Q01	*G1* *G2*	3.97 3.36	0.85 1.14	0.75 1	2 1	4 3	4 3	4.75 4	5 5	30 22	**0.0374**
Q02	*G1* *G2*	3.77 3.32	1.01 1.29	1 1.75	2 1	3 2.25	4 3	4 4	5 5	30 22	0.2111
Q03	*G1* *G2*	3.00 3.14	1.14 1.13	2 2	1 1	2 2	3 3	4 4	5 5	32 22	0.6750
Q04	*G1* *G2*	4.38 4.77	1.16 0.43	1 0	1 4	4 5	5 5	5 5	5 5	32 22	0.3466
Q05	*G1* *G2*	4.25 4.59	1.16 0.67	1.25 1	1 3	3.75 4	5 5	5 5	5 5	32 22	0.4366
Q06	*G1* *G2*	3.94 4.14	1.13 0.99	2 1	1 2	3 4	4 4	5 5	5 5	32 22	0.5759
Q07	*G1* *G2*	4.16 4.64	0.68 0.49	1 1	3 4	4 4	4 5	5 5	5 5	32 22	**0.0091**
Q08	*G1* *G2*	4.03 3.82	0.86 1.10	2 2	2 1	3 3	4 4	5 5	5 5	32 22	0.5719
Q09	*G1* *G2*	3.72 4.00	0.89 0.82	1 0.75	2 2	3 4	4 4	4 4.75	5 5	32 22	0.2188
Q10	*G1* *G2*	4.00 3.86	1.11 0.99	2 1.5	1 2	3 3.25	4 4	5 4.75	5 5	32 22	0.5054

*sd = standard deviation, IQR = interquartile range, n = number of participants, bold values indicate significant differences

TABLE 9. Questionnaire scores by examination sitting, with p-values.

		mean	sd*	IQR*	Percentiles 0 %	25 %	50 %	75 %	100 %	n*	p-value
Q01	First Subsequent	3.80 3.00	0.96 1.26	1 0	1 1	3 3	4 3	4 3	5 5	46 6	0.0785
Q02	First Subsequent	3.67 2.83	1.08 1.47	1 1.75	1 1	3 2	4 2.5	4 3.75	5 5	46 6	0.1449
Q03	First Subsequent	3.08 2.83	1.13 1.17	2 1.5	1 1	2 2.25	3 3	4 3.75	5 4	48 6	0.7217
Q04	First Subsequent	4.48 5.00	0.99 0.00	1 0	1 5	4 5	5 5	5 5	5 5	48 6	0.1189
Q05	First Subsequent	4.42 4.17	1.01 0.98	1 1.75	1 3	4 3.25	5 4.5	5 5	5 5	48 6	0.4082
Q06	First Subsequent	4.00 4.17	1.07 1.17	2 1	1 2	3 4	4 4.5	5 5	5 5	48 6	0.6725
Q07	First Subsequent	4.35 4.33	0.67 0.52	1 0.75	3 4	4 4	4 4	5 4.75	5 5	48 6	0.8189
Q08	First Subsequent	4.00 3.50	0.88 1.52	2 1.75	2 1	3 3	4 3.5	5 4.75	5 5	48 6	0.4777
Q09	First Subsequent	3.88 3.50	0.84 1.05	1.25 1	2 2	3 3	4 3.5	4.25 4	5 5	48 6	0.3742
Q10	First Subsequent	4.00 3.50	1.03 1.22	2 1.5	1 2	3 2.5	4 4	5 4	5 5	48 6	0.3045

*sd = standard deviation, IQR = interquartile range, n = number of participants

the visuospatial skills of learners [41]. However, the imposition of these new tools may discourage inexperienced teachers, and may imply a heavier workload as the learning and testing time increases [42]. Taking advantage of the situation, and being aware that an important part of the teachers are not yet used to e-learning tools, an experiment was performed

TABLE 10. Questionnaire scores by interest in a smartphone version of the platform, with p-values.

		mean	sd*	IQR*	Percentiles 0 %	25 %	50 %	75 %	100 %	n*	p-value
Q01	Yes	3.94	0.90	0	1	4	4	4	5	33	**0.0117**
	No	3.24	1.09	1	1	3	3	4	5	17	
Q02	Yes	3.91	1.01	1	1	4	4	5	5	33	**0.0022**
	No	2.88	1.11	1	1	2	3	3	5	17	
Q03	Yes	3.06	1.07	2	1	2	3	4	5	34	0.7953
	No	2.94	1.21	2	1	2	3	4	5	18	
Q04	Yes	4.62	0.70	1	2	4	5	5	5	34	0.8846
	No	4.33	1.33	0.75	1	4.25	5	5	5	18	
Q05	Yes	4.44	0.79	1	3	4	5	5	5	34	0.9911
	No	4.22	1.35	1	1	4	5	5	5	18	
Q06	Yes	4.03	1.03	2	2	3	4	5	5	34	0.9675
	No	4.00	1.19	1	1	4	4	5	5	18	
Q07	Yes	4.44	0.56	1	3	4	4	5	5	34	0.3232
	No	4.22	0.73	1	3	4	4	5	5	18	
Q08	Yes	4.15	0.74	1	3	4	4	5	5	34	0.2082
	No	3.67	1.24	2	1	3	4	5	5	18	
Q09	Yes	3.88	0.73	1	3	3	4	4	5	34	0.7286
	No	3.72	1.07	1.75	2	3	4	4.75	5	18	
Q10	Yes	4.21	0.88	1	2	4	4	5	5	34	**0.0211**
	No	3.44	1.20	1	1	3	3.5	4	5	18	

*sd = standard deviation, IQR = interquartile range, n = number of participants, bold values indicate significant differences

to evaluate whether the methodologies are changing for the better. In this experiment, a course on building systems was designed using the SAPIENS e-learning platform, where both the content creation process and the automatic correction strategies were taken into account to shorten the required time. The SAPIENS platform was created with the purpose of easing teachers' tasks while providing a high image interaction to students. Therefore, before approaching 3D models, the learning material was only composed of 2D images with which the students could interact, as it was considered to be easier for a trial test. The teacher who designed the course and the tests used the proposed e-learning platform for the first time, and it met his expectations, being able to quickly prepare the theory contents and the interactive exercises. In this study, the effectiveness and the acceptance of the course has been analysed by means of a pre- and a posttest, and a questionnaire.

Looking at the tests' scores, there are obviously significant differences between the pretest and the posttest, regardless of the group. This implies that there was an effective learning process between the two tests. Differently, if the scores are analysed by group, *G1* and *G2* present similar results for the pretest, with clearly no significant differences. This ensures that both groups started from the same level of knowledge, which is a key fact to track their evolution. However, when focusing on the posttest, *G1* scores slightly better than *G2*, with nearly significant differences, considering that the significance level chosen by convention is $\alpha = 0.05$. As *G1* participants correspond to the ones that used the e-learning platform during the whole learning process, this may imply that the use of this e-learning methodology favours the acquisition of knowledge by engaging the students and by encouraging them to learn. It is possible that with a slightly larger sample and by reducing the difficulty of the exercises the differences could be significant.

Focusing on the questionnaire, the results show that *G1* globally rates better than *G2*, possibly because they had the full experience with the platform and they saw their improvement reflected in the scores. For this same reason, the more specific questions may have been rated slightly worse because their use of the functionalities was more relevant to get a good score in the posttest, so they can be more critical; for example, having to repeat the exercises many times may have penalised. In a similar way, *G2* rates the specific questions slightly better than *G1*, as they carried out the course voluntarily after the posttest, meaning that they may have liked some of the functionalities or the design and they wanted to practise more. When analysing by age, bachelor's degree and subject, no significant differences are found, implying that the content of the course is interdisciplinary and general enough. However, even though no significant differences can be found either, when the analysis is performed comparing by the examination sitting, a trend can be perceived for the repeat students, who rate a little worse. This may stem from the fact that these students are somewhat more unmotivated, since they have already studied the subject at least once [43]. Taking into account the technology-related characteristics, the SAPIENS platform can be considered well adapted to any participant profile as no significant differences were found between those participants with little or no experience in online courses and those who had previously attended many of them. Finally, there is a clear difference in the rating scores for those participants interested in a smartphone version of the platform, who rated certainly better probably because they are more engaged and enthusiastic for new technologies and enjoy the proposed methodology. Therefore, it is clear that an m-learning approach would be much more appealing to participants who have already experimented with an interactive methodology such as the one proposed in this study, since they have been aware of the advantages it provides.

Overall, the hypothesis raised at the beginning of the study can be confirmed, as the students improved their performance after using the interactive platform and the results did not worsen compared to the classical methodology (in fact, they were slightly better), and there was a high level of satisfaction from all participants, thus demonstrating the motivating potential of the proposed methodology.

Although the results indicate that the proposed e-learning methodology is both effective and motivating, some limitations of the study should be stated. As for the content of the course, some of the exercises were found to be excessively complicated, either by the intrinsic difficulty of the exercises or by the acceptance threshold for the region-drawing exercises, which was perhaps too high. Indeed, almost no participant passed the posttest, and this may have led to poor results and frustration. Regarding the usability of the platform, the main concern of the participants was the time required to draw a polyline; drawing one of them accurately takes time, so when there are multiple regions to draw in a single exercise, and when the exercises have to be repeated due to an incorrect answer, tiredness may arise. If, besides, there is an excess of exercises (20 for each test, and 50 for the course), all these limitations are intensified. Therefore, as a future work the number of exercises should be lessened, their difficulty decreased (by reducing the acceptance threshold for some exercises, for instance), and the usability improved, maybe with the possibility to restore the student-drawn regions of the last submitted answer.

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REFERENCES

[1] J. Ferrer, A. Ringer, K. Saville, M. A. Parris, and K. Kashi, "Students' motivation and engagement in higher education: The importance of attitude to online learning," *Higher Educ.*, vol. 83, pp. 317–338, Feb. 2022, doi: 10.1007/s10734-020-00657-5.

[2] M. Assunção Flores and M. Gago, "Teacher education in times of COVID-19 pandemic in Portugal: National, institutional and pedagogical responses," *J. Educ. Teaching*, vol. 46, no. 4, pp. 507–516, Jul. 2020, doi: 10.1080/02607476.2020.1799709.

[3] J. König, D. J. Jäger-Biela, and N. Glutsch, "Adapting to online teaching during COVID-19 school closure: Teacher education and teacher competence effects among early career teachers in Germany," *Eur. J. Teacher Educ.*, vol. 43, no. 4, pp. 608–622, Aug. 2020, doi: 10.1080/02619768.2020.1809650.

[4] B. L. Moorhouse, "Adaptations to a face-to-face initial teacher education course 'forced' online due to the COVID-19 pandemic," *J. Educ. Teaching*, vol. 46, no. 4, pp. 609–611, Apr. 2020, doi: 10.1080/02607476.2020.1755205.

[5] R. Hämäläinen, K. Nissinen, J. Mannonen, J. Lämsä, K. Leino, and M. Taajamo, "Understanding teaching professionals' digital competence: What do PIAAC and TALIS reveal about technology-related skills, attitudes, and knowledge?" *Comput. Hum. Behav.*, vol. 117, Apr. 2021, Art. no. 106672, doi: 10.1016/j.chb.2020.106672.

[6] S. Seufert, J. Guggemos, and M. Sailer, "Technology-related knowledge, skills, and attitudes of pre- and in-service teachers: The current situation and emerging trends," *Comput. Hum. Behav.*, vol. 115, Feb. 2021, Art. no. 106552, doi: 10.1016/j.chb.2020.106552.

[7] H. M. Niemi and P. Kousa, "A case study of students' and teachers' perceptions in a Finnish high school during the COVID pandemic," *Int. J. Technol. Educ. Sci.*, vol. 4, no. 4, pp. 352–369, Sep. 2020, doi: 10.46328/ijtes.v4i4.167.

[8] I. van der Spoel, O. Noroozi, E. Schuurink, and S. van Ginkel, "Teachers' online teaching expectations and experiences during the COVID19-pandemic in The Netherlands," *Eur. J. Teacher Educ.*, vol. 43, no. 4, pp. 623–638, Sep. 2020, doi: 10.1080/02619768.2020.1821185.

[9] H. Crompton, "A historical overview of mobile learning: Toward learner-centered education," in *Handbook of Mobile Learning*, 1st ed., Z. L. Berge and L. Y. Muilenburg, Eds. New York, NY, USA: Routledge, Apr. 2013, ch. 1, pp. 3–14.

[10] M. Al-Emran, V. Mezhuyev, and A. Kamaludin, "Technology acceptance model in M-learning context: A systematic review," *Comput. Educ.*, vol. 125, pp. 389–412, Oct. 2018, doi: 10.1016/j.compedu.2018.06.008.

[11] D. R. Garrison, *E-Learning in the 21st Century: A Framework for Research and Practice*, 2nd ed. New York, NY, USA: Routledge, 2011.

[12] A. K. M. N. Islam, "E-learning system use and its outcomes: Moderating the role of perceived compatibility," *Telematics Inform.*, vol. 33, no. 1, pp. 48–55, Feb. 2016, doi: 10.1016/j.tele.2015.06.010.

[13] H. Rodrigues, F. Almeida, V. Figueiredo, and S. L. Lopes, "Tracking e-learning through published papers: A systematic review," *Comput. Educ.*, vol. 136, pp. 87–98, Jul. 2019, doi: 10.1016/j.compedu.2019.03.007.

[14] A. Agirbas, "Teaching construction sciences with the integration of BIM to undergraduate architecture students," *Frontiers Architectural Res.*, vol. 9, no. 4, pp. 940–950, Dec. 2020, doi: 10.1016/j.foar.2020.03.007.

[15] H. G. Bayhan and E. Karaca, "Technological innovation in architecture and engineering education—An investigation on three generations from Turkey," *Int. J. Educ. Technol. Higher Educ.*, vol. 17, no. 1, p. 33, Aug. 2020, doi: 10.1186/s41239-020-00207-0.

[16] R. E. Mayer, "Multimedia learning: Guiding visuospatial thinking with instructional animation," in *The Cambridge Handbook of Visuospatial Thinking* (Cambridge Handbooks in Psychology), P. Shah and A. Miyake, Eds. Cambridge, U.K.: Cambridge Univ. Press, 2005, pp. 477–508.

[17] B. Sidawi, "The use of E-learning system in learning about architecture: Obstacles and opportunities," in *Proc. 5th Int. Conf. e-Learn. (econf)*, New York, NY, USA, Oct. 2015, pp. 117–124, doi: 10.1109/ECONF.2015.13.

[18] J. Y. Cho, "An investigation of design studio performance in relation to creativity, spatial ability, and visual cognitive style," *Thinking Skills Creativity*, vol. 23, pp. 67–78, Mar. 2017, doi: 10.1016/j.tsc.2016.11.006.

[19] F. J. Sabongi, "The integration of BIM in the undergraduate curriculum: An analysis of undergraduate courses," in *Proc. 45th ASC Annu. Int. Conf.*, Gainesville, FL, USA, T. Sulbaran and C. Sterling, Eds. Apr. 2009, pp. 1–6.

[20] M. M. Joannides, S. Olbina, and R. R. A. Issa, "Implementation of building information modeling into accredited programs in architecture and construction education," *Int. J. Construction Educ. Res.*, vol. 8, no. 2, pp. 83–100, Apr. 2012, doi: 10.1080/15578771.2011.632809.

[21] D. Zhao, A. P. McCoy, T. Bulbul, C. Fiori, and P. Nikkhoo, "Building collaborative construction skills through BIM-integrated learning environment," *Int. J. Construct. Educ. Res.*, vol. 11, no. 2, pp. 97–120, Jan. 2015, doi: 10.1080/15578771.2014.986251.

[22] W. Abdelhameed, "BIM in architecture curriculum: A case study," *Architectural Sci. Rev.*, vol. 61, no. 6, pp. 480–491, Jun. 2018, doi: 10.1080/00038628.2018.1483888.

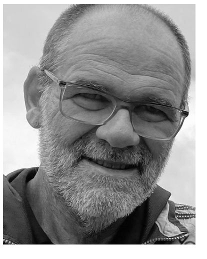
[23] S. Suwal and V. Singh, "Assessing students' sentiments towards the use of a building information modelling (BIM) learning platform in a construction project management course," *Eur. J. Eng. Educ.*, vol. 43, no. 4, pp. 492–506, 2017, doi: 10.1080/03043797.2017.1287667.
[24] N. Ham, S. Moon, J.-H. Kim, and J.-J. Kim, "Optimal BIM staffing in construction projects using a queueing model," *Autom. Construct.*, vol. 113, May 2020, Art. no. 103123, doi: 10.1016/j.autcon.2020.103123.
[25] R. T. Azuma, "A survey of augmented reality," *Presence*, vol. 6, no. 4, pp. 355–385, 1997, doi: 10.1162/pres.1997.6.4.355.
[26] L. Chittaro and R. Ranon, "Web3D technologies in learning, education and training: Motivations, issues, opportunities," *Comput. Educ.*, vol. 49, no. 1, pp. 3–18, Aug. 2007, doi: 10.1016/j.compedu.2005.06.002.
[27] T. Monahan, G. McArdle, and M. Bertolotto, "Virtual reality for collaborative e-learning," *Comput. Educ.*, vol. 50, no. 4, pp. 1339–1353, 2008, doi: 10.1016/j.compedu.2006.12.008.
[28] E. A. O'Connor, "Open source meets virtual reality—An instructor's journey unearths new opportunities for learning, community, and academia," *J. Educ. Technol. Syst.*, vol. 44, no. 2, pp. 153–170, Dec. 2015, doi: 10.1177/0047239515617158.
[29] A. Z. Sampaio, M. M. Ferreira, D. P. Rosário, and O. P. Martins, "3D and VR models in civil engineering education: Construction, rehabilitation and maintenance," *Autom. Construct.*, vol. 19, no. 7, pp. 819–828, Nov. 2010, doi: 10.1016/j.autcon.2010.05.006.
[30] Y. Zhang, H. Liu, S.-C. Kang, and M. Al-Hussein, "Virtual reality applications for the built environment: Research trends and opportunities," *Autom. Construct.*, vol. 118, Oct. 2020, Art. no. 103311, doi: 10.1016/j.autcon.2020.103311.
[31] C. Zhang and B. Chen, "Enhancing learning and teaching for architectural engineering students using virtual building design and construction," *Higher Educ. Stud.*, vol. 9, no. 2, pp. 45–56, Feb. 2019, doi: 10.5539/hes.v9n2p45.
[32] J. M. Davila Delgado, L. Oyedele, P. Demian, and T. Beach, "A research agenda for augmented and virtual reality in architecture, engineering and construction," *Adv. Eng. Informat.*, vol. 45, Aug. 2020, Art. no. 101122, doi: 10.1016/j.aei.2020.101122.
[33] J. Du, Z. Zou, Y. Shi, and D. Zhao, "Zero latency: Real-time synchronization of BIM data in virtual reality for collaborative decision-making," *Autom. Construct.*, vol. 85, pp. 51–64, Jan. 2018, doi: 10.1016/j.autcon.2017.10.009.
[34] V. Getuli, P. Capone, A. Bruttini, and S. Isaac, "BIM-based immersive virtual reality for construction workspace planning: A safety-oriented approach," *Autom. Construct.*, vol. 114, Jun. 2020, Art. no. 103160, doi: 10.1016/j.autcon.2020.103160.
[35] A. Kamari, A. Paari, and H. Ø. Torvund, "BIM-enabled virtual reality (VR) for sustainability life cycle and cost assessment," *Sustainability*, vol. 13, no. 1, p. 249, Dec. 2020, doi: 10.3390/su13010249.
[36] C. J. Van Rijsbergen, "Foundation of evaluation," *J. Document.*, vol. 30, no. 4, pp. 365–373, Apr. 1974, doi: 10.1108/eb026584.
[37] C. J. van Rijsbergen, *Information Retrieval*, 2nd ed. London, U.K.: Butterworths, 1979.
[38] R. Likert, "A technique for the measurement of attitudes," *Arch. Psychol.*, vol. 22, no. 40, pp. 5–55, Jun. 1932.
[39] *American Educational Research Education, Americal Psychological Association, and National Council on Measurement in Education, Standards for Educational and Psychological Testing*, American Educational Research Education, Washington, DC, USA, 2014.
[40] J. C. F. de Winter, D. Dodou, and P. A. Wieringa, "Exploratory factor analysis with small sample sizes," *Multivariate Behav. Res.*, vol. 44, no. 2, pp. 147–181, Apr. 2009, doi: 10.1080/00273170902794206.
[41] H. C. Gómez-Tone, J. Martin-Gutierrez, J. Bustamante-Escapa, and P. Bustamante-Escapa, "Spatial skills and perceptions of space: Representing 2D drawings as 3D drawings inside immersive virtual reality," *Appl. Sci.*, vol. 11, no. 4, p. 1475, Feb. 2021, doi: 10.3390/app11041475.
[42] Sangeeta and U. Tandon, "Factors influencing adoption of online teaching by school teachers: A study during COVID-19 pandemic," *J. Public Affairs*, vol. 21, no. 4, p. e2503, Nov. 2021, doi: 10.1002/pa.2503.
[43] G. Abío, M. Alcañiz, M. Gómez-Puig, G. Rubert, M. Serrano, A. Stoyanova, and M. Vilalta-Bufí, "Retaking a course in economics: Innovative teaching strategies to improve academic performance in groups of low-performing students," *Innov. Educ. Teach. Int.*, vol. 56, no. 2, pp. 206–216, 2019, doi: 10.1080/14703297.2017.1389289.

PAU XIBERTA received the B.Sc. degree in computer science from the Universitat de Girona (UdG), Girona, Catalonia, the M.Sc. degree in computer science from the Universitat Oberta de Catalunya, Barcelona, Catalonia, and the Ph.D. degree in technology from UdG.

He is currently a Postdoctoral Researcher with the Graphics and Imaging Laboratory and the Computer Science and Applied Mathematics Department, UdG. His research interests include e-Learning and image processing.

SANTIAGO THIÓ-HENESTROSA received the B.Sc. and Ph.D. degrees in computer science from the Universitat Politècnica de Catalunya, Barcelona, Catalonia.

He is currently a tenured University Lecturer with the Computer Science and Applied Mathematics Department, Universitat de Girona, Girona, Catalonia, and a Researcher with the Research Group on Statistics and Data Analysis, Girona. His research interest includes compositional data analysis.



JOAN FONTÀS received the B.Sc. degree in arquitectural technology from the Escola Universitària Politècnica de Girona, Girona, Catalonia, and the B.Sc. degree in architecture from the Escola Superior d'Arquitectura de Barcelona, Barcelona, Catalonia.

He is currently a Permanent Collaborating Lecturer with the Architecture and Construction Engineering Department, Universitat de Girona, Girona, and a Researcher with the UdiGitalEdu: Creative Learning, STEAM and Social Change Research Group, Girona, where he is also working on his Ph.D. thesis on learning about construction through images.

IMMA BOADA received the M.Sc. degree in computer science from the Universitat Autònoma de Barcelona, Bellaterra, Catalonia, and the Ph.D. degree in computer science from the Universitat Politècnica de Catalunya, Barcelona, Catalonia.

She is currently a Professor with the Computer Science and Applied Mathematics Department, Universitat de Girona, Girona, Catalonia, and a Researcher with the Graphics and Imaging Laboratory, Girona, where she carries out research and development on visualization, image processing, serious games, and e-Learning.