Technological adaptation of the student to the educational density of the course. A case study: 3D Architectural Visualization

ABSTRACT

The main objective of this study was to assess the degree of students' adaptation to two types of courses on applications of architectural spatial representation. With the same lengths, the first proposal involved lectures on 4-5 applications, whereas the second covered approximately 20 applications, all of which were focused on the three-dimensional architectural (3D) representation. Both proposals were based on applications and technological innovations that allow better use of active learning, which is the basis of architectural education. After an initial study of the students' profiles and motivations, both courses were implemented and quantitative and qualitative data were collected. This mixed approach provided us with a better understanding of the results of students' motivation and satisfaction. The results confirm how the learning process based on a high number of applications can stress the student, and with smaller number of applications and more time for explanations we obtain a greater effectiveness in the process, increasing the final motivation and satisfaction of the students.

Keywords: Technological skills assessment; user experience; student motivation; mixed methods assessment; student behavior.

1. Introduction

Information and communications technologies (ICTs) have revolutionized our society and, consequently, education (Dede, 2000). Currently, the ways we communicate, consult the news, watch television or simply play have been changing and adapting to new devices and applications that mostly involve characteristics such as mobility, interaction and interconnection. Nonetheless, in different areas of knowledge, education has failed to adapt to these changes. It is still easy, if not common, to find examples of the traditional class or lecture class being presented as the predominant system. In such cases, this problem can be magnified because the student is no longer a traditional student but rather exactly the contrary: he/she has been born into a "digital age". As a "digital native" (Bennett, Maton & Kervin, 2008), he/she is capable of adapting and quickly using all types of devices and applications for his/her own purposes, and not using these can negatively influence his/her attention and comprehension.

From our initial assumption, the two hypotheses that we investigated in our work are clear. On the one hand, we evaluated the degree of adaptation (which was assumed to be high) of a "digital native" to a steady stream of technological elements applied to his/her education. On the other hand, we evaluated whether the implementation of new educational models based on the use of new visualization technologies would generate greater motivation/satisfaction in the student, and we evaluated the effects of a system based on a high density of superficial explanations compared with a much more detailed traditional system. The validation of these hypotheses, together with the results from various previous studies (Redondo, Fonseca, Giménez, Santana & Navarro, 2012; Fonseca, Martí, Redondo, Navarro & Sánchez, 2014), will allow us to confirm that an improvement in motivation leads to greater academic achievement in the student and, consequently, his/her preparation for the professional world. In particular, we believe it is important to continue generating knowledge about the technological behavior of the student in light of teaching innovations. As mentioned before, there are increasing innovations in education, and they are being applied broadly but, in many cases, improperly (Rodriguez-Izquierdo, 2010). Not every educational innovation that necessitates the use of technology involves educational improvement, and undoubtedly, the student's behavior is a key factor that should be controlled for (Liljequist & Renk, 2007).

The scope of the work in which this educational project was designed was limited to coursework for the degree in architecture. This degree and its implementation in Spain is paradigmatic within the European Higher Education Area (EHEA) for various reasons: It was designed as a 6-year degree (12 semesters, much longer than traditional degrees, which require 3 or 4 years with 6 to 8 semesters); it has a high number of professors of advanced age in all of its departments; and in recent years, new building regulations and project approvals have required the incorporation of technical elements only available using very specific applications and with little training throughout the degree. Therefore, we can state that due to the teaching and research experience of the teaching faculty, a student who completes this degree has high competence in the most traditional aspects of architecture and construction, such as those regarding structures, installations, urban planning, materials, and project design (Åkerlind, 2003; Aguilar, 2004). The student, however, has great deficiencies in producing three-dimensional (3D) content that enables the interactive visualization of a project and, thus, a better presentation of the work, which corresponds to a digital divide that increases with age (Maroto, 2007). These skills are especially important in the professional field of architecture because the ability to explain a project and adequately convey ideas to a final client are undoubtedly variables that impact validity in any project (Bouchlaghem, Shang, Whyte, & Ganah, 2005).

As has been argued and to improve skills in the 3D representation of architectural projects, two courses with different methodologies were designed using a Project-Based Learning (PBL) approach. This approach involves producing a real presentation of a selected architectural project, one of the competencies and skills that students with the degree should actively possess (Banerjee & Graaff, 1996; Maitland, 1997). In one of the proposals, the characteristics of 4-5 applications were explored in depth, whereas the other proposal involved the use of many more applications and devices (approximately 20), with the very specific selection of the most useful aspects for the project's representation. Whereas the first method involves a moderate pace of explanation, the second proposes extracting the most useful and practical elements from each system for a workflow that is much faster and focused on the final deliverable. Logically, for the second method, it is assumed that greater stress in the student should not influence the degree of motivation, whereas for the first case, the opposite may occur: if a student's motivation is high, a slow workflow can produce boredom and the opposite of the desired effect: a lack of motivation.

To analyze the proposed methods and assess the degree to which they were accepted, we used a formula for data extraction that was previously validated in other educational studies in the same field (Fonseca, Valls, Redondo & Villagrasa, 2016; Fonseca, Redondo & Villagrasa, 2015). An initial pre-test was conducted to obtain the student's profile and starting level of motivation/knowledge about the use of selected technologies. At the end of the course, a post-test was conducted to assess the level of satisfaction and completed use of each system, and a personal interview was conducted using the Bipolar Laddering (BLA) technique (Pifarré & Tomico, 2007), which allows us to identify and quantify the strong and weak points of the proposed methods. The current proposal has a clear line of continuation in future iterations because it reveals correlations between statistical results and final grades in a way that allows us to evaluate the relationships between different variables in the study and the student's improvement. This proposal also allows us to form conclusions in the future that can be extrapolated and validated in other areas of knowledge. Likewise, the mixed approach will allow us to extract data and identify noteworthy and adaptable aspects in future iterations of the proposed system.

2. Literature Review

2.1 ICTs in education

As previously described, there are numerous examples from recent years of the incorporation of all types of applications and systems into classrooms at all educational levels to improve teaching, especially to improve student motivation. In preschool and early childhood education, the use of digital chalkboards and very basic web applications are enabling new ways to teach subjects such as math, languages, and science (Beauchamp & Parkinson, 2008; Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt & Wenderoth, 2014). In primary school, the increasingly complex use of computers and applications, which recently has even included the programming of robots, are innovations that directly impact the attention and comprehension levels of students, where the technological and social profiles of the student begin to illuminate the final answer (Volman, Eck, Heemskerk & Kuiper, 2005; Petre & Price, 2004). Beginning in secondary school, there is a challenge to incorporate mobile devices belonging to students, such as smartphones and tablets, into educational use through collaborative practices (and even gaming methods) that complement their social use (Leask and Pachler, 2013).

In conclusion, when current students reach a new grade level, they typically are experts not only in the use of all types of computer applications but also in the use of ubiquitous systems of work; at least, this is assumed of them (Margaryan, Littelejohn & Voit, 2011, Pereira, Martins, Gonçalves & Santos, 2014). In any case, educators should take advantage of students' digital proficiency and incorporate it into academic plans to avoid a generational gap in terms of course contents, teachers and, ultimately, education in general.

The use of ICTs in educational methods is defined in the curricula of many undergraduate and master's degrees, including the architecture degree, the focus of this study (Sariyildiz & Van der Veer, 1998; Tinio, 2003; Reffat, 2007). These descriptions indicate that the student be able to acquire both personal and collaborative competencies and skills related to active learning, as well as information management, through applications and devices that enable the adoption of PBL. These methods should allow students to work using specific and effective roles much more quickly than with traditional systems and should be able to apply them in their work environment in the future. For all of these reasons, it is necessary to propose and implement new methods through a PBL system, including the use of appropriate technologies that enable the student to more optimally dedicate him/herself to project and time management.

The adaptation of contents and their applications to ubiquitous learning in the fields of architecture, construction and urban design, all focusing on the student and his/her levels of motivation and satisfaction, has been studied quite recently (Sánchez, Redondo & Fonseca, 2015). Typically, studies focused on evaluating pedagogical innovations and student response have been focused on pre-university education, particularly in fields such as science and math (Shen, Liu & Wang, 2013, Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt & Wenderoth, 2014, Cota, Thomaschewski, Schrepp & Gonçalves, 2014). In areas such as architecture, research has traditionally focused on the student's ability to design projects. This focus is based on the requirement that these projects comply with new digital standards when testing the need to incorporate new teaching systems that respond to this demand because a good project can be invalid if it does not meet the imposed standards of presentation and visualization.

2.2 Technological innovation in architectural education

First, we must approach the world and teaching of architecture as a component of traditional teaching, which also includes law, medicine, the fine arts and politics. From this perspective, drawing, painting and photography would be precursors to the main technological innovation incorporated at the educational and professional levels: the computer and the use of CAD (Computer-Assisted Design) applications (Mitchell, 1977; Ullman, Wood & Craig, 1990). The following evolution is much more recent and is, in a sense, the cause of the current changing landscape and great need for much broader training in all types of technologies: the appearance of BIM (Building Information Modeling) (Barison & Santos, 2010; Azhar, 2011; Sanguinetti, Abdelmohsen, Lee, Lee, Sheward & Eastman, 2012).

Traditional proposals, CAD, the more recent BIM, and other techniques, such as digital sketching (DS) and digital infographics (also known as digital graphics, DG), are all aimed at solving one of the main problems in architecture: the modelling and visualization of complex elements. The acquisition and representation of data associated with land are complex and incompletely documented aspects of modelling (Fassi, 2007).

The currently available solutions focus on the basic ability to develop an architectural plan, rather than maximum accuracy in representing the geometry of buildings. In this regard, recent advances in applications of automated digital photogrammetry can compete performance-wise with laser scanners due to their low cost and use with all types of computers. Nonetheless, automated digital photogrammetry systems can only work over short distances (approximately 25 meters) and under good lighting conditions or with very bright optics (Grussenmeyer & Hanke, 2002; Hullo, Grussenmeyer & Fares, 2009).

The various applications available on the market often incorporate modules specializing in dense stereo matching (DSM) methods, which were widely used in previous studies (Hannah, 1989; Hoff & Ahuja, 1989). With all of these processes, it is necessary to correctly calibrate the cameras and to use multiple images to semi-automatically (or even manually, on occasion) correlate each represented element and base photograph (Guidi, Beraldin & Atzeni, 2004; Yang & Wu, 2008; Zenati & Zerbouni, 2007). However, we have recently identified new applications that use graphics processing unit (GPU) systems, for which camera calibration is unnecessary but more images and objects with good lighting are required. These methods, known as structure from motion (SFM), are especially suitable for modeling buildings with predominantly curved elements or geometry (Lhuillier & Quan, 2005; Wu, Yeung, Jia & Tang, 2010).

A second aspect to consider is 3D architectural rendering, particularly because new forms and systems of visualization often exceed the possibilities of traditional CAD solutions and even BIM. From an academic viewpoint, these systems are used to improve the acquisition of skills and spatial competencies to analyze the visual impact of any building or architectural project. Nonetheless, the problem resides in the fact that this teaching exercise, usually based on CAD or BIM applications, is not always the most appropriate. Other systems that would allow a better understanding and validation of the space are not explored, although they would be very useful at the professional level. In this regard, systems and formats such as HTML5 allow us to easily transfer models to mobile devices (Doodey & Hanlon, 2014). These types of formats add a ubiquitous component to educational processes (Zheng, Cheng & Peng, 2015), which can be associated with the use of augmented reality (AR) (Oat, Francesco & Aura, 2014), virtual reality (VR) (Gero & Zoabi, 2014; Yan, Culp & Graf, 2011), and all types of techniques that help describe building processes through dynamic visualizations, such as PDF3D (Gutiérrez, Dominguez & González, 2015; Breuel, Berndt, Ullrich, Eggeling & Fellner, 2011).

Finally, we describe the recent increase in popularity of new educational experiences based on "FabLab" systems (Mikhak, Lyon, Gorton, Gershenfeld, McEnnis, & Taylor, 2002; Mostert-Van, Mulder, Remijn, Troxler, 2013; Blikstein, & Krannich, 2013) or on the use of CAD/CAM processes (Overend & Bassett, 1987; Reed, 2011; D'Agnano, Balletti, Guerra & Vernier, 2015). However, because of high costs and the need for specialized machinery, these systems have not been implemented to the degree desired.

2.3 Technological behavior of the student: emotional response to teaching innovations

Considering previous recommendations and logical assumptions based on cognitive studies, such as that by Gantt (1998), we can state that humans have a low capacity for retention, which varies greatly depending on how they experience their surroundings. It is widely recognized that approximately 25% of what we hear is retained, a proportion that increases to 75% if a specific action is performed. Based on these results, it seems vitally important to move from the traditional lecture class to other models that produce a higher rate of retention. Undoubtedly, this paradigm shift sustains the PBL concept and other, more generic concepts, such as Internet 2.0 or 3.0, which allow the user (in our case, the student) to transition from a passive consumer to an active generator of content.

Systems such as Wikipedia, social networks and various technological innovations in general (especially mobile devices) have improved the processes of interaction and every type of learning by users to access content in a friendly way. In this regard, numerous types of studies have linked the use of ICTs with improved student motivation and, correspondingly, academic performance (Callaway, 2009; Fonseca, Martí, Redondo, Navarro & Sánchez, 2014). While focusing on the study of user behavior and emotions, we cannot forget its connection with the area of widely documented knowledge corresponding to user experience and usability (UX). These areas are historically related to the field of human-computer interaction (HCI); from that perspective, it would be interesting to analyze any innovation that involves the use of new computer systems or technologies (Hassenzahl & Tractinsky, 2006).

The behavior of a user of a new system or proposal provides information crucial for the success of its final implementation. To that end, there are quantitative strategies (e.g., usability tests, profile tests, and satisfaction surveys), qualitative strategies (e.g., personal interviews and focus groups), and mixed approaches that combine the use of both quantitative and qualitative techniques.

Quantitative methods are vital for rapidly assessing the key factors from the design perspective that are to be evaluated at the beginning, during, or at the end of the development process. However, by characterizing and providing detail to the quantitative data, qualitative methods provide a point of view that is more subjective and, at times, complementary to the user. Whereas quantitative studies have traditionally been linked to statistical and sociological studies, qualitative approaches have been used in the social sciences and usability research, especially due to the personal input that can characterize highly detailed responses. A combination of both approaches generates what is commonly known as mixed methods research, which has been widely tested and continues to produce study results (see examples in the Journal of Mixed Methods Research), filling gaps in each model and refining the obtained results (Fonseca, Redondo & Villagrasa, 2015).

3. Case Study

As previously mentioned, two courses were designed with different methodologies to evaluate student behavior, motivation and adaptation to pedagogical innovations that involve the use of different work technologies and visualization of complex 3D models. Both courses were designed by a team of educators who teach the Representation Techniques I and II courses at the Superior Technical School of Architecture of La Salle (Universitat Ramon Llull) and the Architectural Representation III and Multimedia courses at the Superior Technical School of Architecture of Barcelona (Universitat Politècnica de Catalunya). The course design was within the timeframe of a grant-based project: “E-learning 3.0 in the teaching of architecture: case studies of educational research for the foreseeable future”.

Both courses were designed from the perspective of PBL, a technology that is easily adapted to the instruction of students in architecture degree programs, who work with real exercises and initiatives from the very outset of their coursework (Schmidt, Loyens, Gorg & Pass, 2007). Also, the courses were designed to evaluate the student's levels of motivation, satisfaction and adaptation to a proposal based on the development of an architectural project.

The first case, course A, was based on the use of CAD/BIM techniques and their interactive presentation in AR/VR, and involved the use of five applications, from the initial modeling to the phase of visualization and final presentation. Course B, based on the same objectives as A, involved learning and using multiple interconnected systems. Course B was based on the premise that a single technology or application is incapable of resolving both the modeling and visualization of complex elements (Fonseca, Redondo, Sánchez, Villagrasa and Martí, 2013), and it explored multiple systems ranging from CAD technology to CAM (computer-aided manufacturing) systems, AR/VR, interactive panoramas, and automatic capture systems, among others. More than 15 applications and systems were used superficially to obtain, in each case, the tool or option of interest for the following step.

The courses were held during the second semester of the 2014-2015 academic year as part of the required courses for the architecture degree. To evaluate the proposed objectives, two surveys were designed. The initial survey assessed the user profile and motivation with the basic objective of evaluating the work groups and the extent of their similarities to validate the differentiation of the experiment and its results. The second survey assessed student satisfaction and the results of the completed experience at the end of the course, which provided us with a measure of behavior differentiated as a function of the course's pace and students' level of adaptation. Additionally, a series of qualitative interviews was conducted using the BLA method to obtain open-ended responses to clarify the quantitative results. The following sections describe the design of each course, followed by the analysis of the results from each phase.

3.1 Course A: Low density

The first designed course, or course A, was based on the development of a project in three phases for interactive visual presentation.

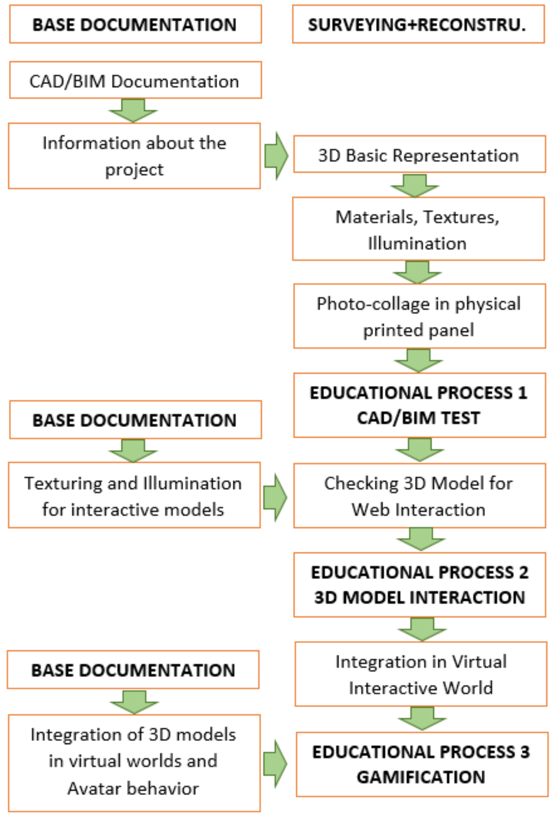

Figure 1. Case A Diagram

The three work phases consisted of the following:

- Basic 3D modeling: In this course, according to academic recommendations, the selected project was the Neue National Gallery (1968), the last project designed by Mies van der Rohe. For this phase, students used Autodesk Revit Architecture software for the basic modeling of the building. Once the basic 3D model was completed, it was imported to 3DMax, where materials and textures were added, and the scene was illuminated. Then, students proceeded to generate a series of photorealistic (or rendered) images from various points of view and with different conditions, such as lighting. Finally, using the Adobe Photoshop image processing package, size A-2 printed panels were prepared that explained the project and free design.

- Advanced 3D modeling: The next step was to integrate the model of the building produced in the first phase into a virtual location that allowed the exterior and interior navigation of the 3D model. For this process, the model was exported in .FBX format and was integrated into the Cl3ver platform. This platform allows the user to confirm that the created model is correct and to integrate it into complex environments. If the system validates the model, it can be satisfactorily integrated as a 3D design into the virtual and collaborative environment during the final phase.

- Interactive virtual presentation: Once the model's textures and materials had been corrected based on the indications and errors found in phase 2, the student exported the corrected model in .FBX format. This model considers the space allocated for the placement of the proposal and that it was previously designated in class. Then, using Unity (an engine traditionally used in videogames and 3D navigation systems), the building was integrated into a corresponding area, and so on for each work group. Thus, a first-person game was defined wherein the "Avatar" or character could three-dimensionally walk, jump and visit the location and each proposal. In this way, one could collaboratively share and assess each proposal; each team's progress is clearer, and optimal solutions are identified in each case.

All of the applications have free student licenses or trial licenses, or the school computers have applications 100% enabled for use, allowing actual implementation by students at no cost.

3.2 Course B: High density

The proposed project comprised three groups of complex practices guided by experts in the use of the required equipment, such as laser scanners, UAVs (unmanned aerial vehicles), 3D printers, AR glasses (e.g., Google Glass), or VR devices (e.g., Oculus Rift) (Fig. 2).

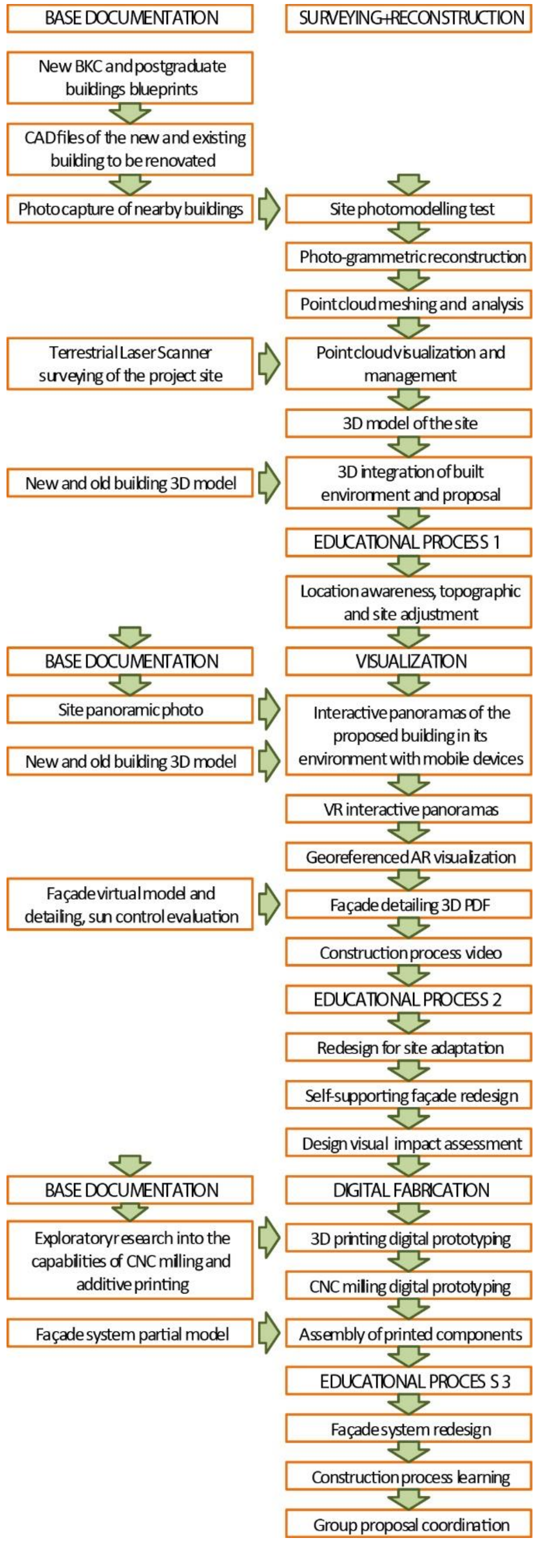

Figure 2. Case B Diagram

The project chosen for this case study was the expansion of one of the buildings of the Barcelona Knowledge Campus (BKC) on the grounds of the Universitat Politècnica de Catalunya (UPC). Because this course was a workshop developed in the final part of the course, students were expected to be capable of establishing the appropriate links between the various technologies to achieve a viable proposition when working on the project. The development of each practice, including lectures and presentations, composed approximately one-third of the course.

The aim of the first practice was to document and simulate the real environment where the project would be located using ICT techniques based on photo-modeling and analysis of digital images. To this end, students would be trained in the documentation of basic elements, buildings or urban complexes of interest using Dense Surface Modelling (DSM) or structure from motion (SFM) techniques. In this phase, the goal was to use the low- cost applications and utilities available to the students. With the initial data and the available documentation on BKC, a virtual model of the subject of study was developed. At this stage, the use of the following applications was proposed:

- 123DCatch to introduce the use of SFM
- PhotoScan to improve meshing, apply textures and facilitate export to other applications
- PhotoModeler Scanner for the precise removal of repetitive elements
- Autodesk ReCap to display point clouds acquired with a laser scanner
- Cloud Compare to cut point clouds
- Rhinoceros to generate meshes from point clouds
- Applications such as SketchUp, 3D Studio or AutoCAD to generate the final virtual models

To determine the geometry of the rooftops of the buildings, UAVs equipped with compact digital cameras were used. The captured images were added to the restitution processes mentioned above.

The objective of the second practice focused on evaluating the visual impact and describing the construction process of the proposed building, especially its self-supporting facade. Through the generation of the virtual model and the use of AR and VR objects, mobile devices were used to visualize the façade details and constructive system. The deliverables of this phase were interactive panoramas, PDF3D format files and animations displaying the construction process of the façade. The following applications were proposed:

- Photoshop for image editing and the creation of panoramas
- PTGui, Photosynth, and others, such as PTlens or DXOptics to adjust the captured images
- Ivist3D or KrPano to adjust the panoramas
- KrPano to generate the HTML code to allow viewing on mobile devices or virtual reality
- iVisit Builder to configure the content for Android or iOS platforms
- Photoshop Extended and Microstation for generating the PDF3D models
- Artlantis and 3DStudio for the final animation

In parallel, a virtual model of the building was displayed using AR with SketchUp plugin.

The third practice was dedicated to simulating the construction process of the façade model by introducing CAD/CAM. The main features of this phase were as follows:

- 3D printing of technological elements of the project at different scales and the assembly of obtained parts using strategies such as additive and subtractive processes
- Use of different applications that allow the creation of physical 3D models of simple models and 3D printing: 123DMake, MeshMixer, MeshLab, Pepakura and Rhinoceros

We must stress that the approach was based on the use of demo and/or educational licenses; thus, the practice did not burden the students with additional expenses.

4. Results

4.1 Pre-test and user profile

Once the courses and supporting documentation had been designed, the first direct action completed was to evaluate student profiles. Two main aspects were analyzed:

- Ability to implement the proposed methodology: The pre-test was designed to ask students about the technologies they are familiar with, possess or use. With these data, we can identify the level of advanced preparation in using interconnected systems through different devices such as computers, mobile phones, tablets, large-format printers, digital cameras, and GPS. A classical mistake is assuming the presence of knowledge, use or possession of technologies required to complete a project; when this assumption is later proved wrong, the experiment fails due to design errors in the implementation and development processes.
- The level of initial motivation and perceived usefulness in applying the proposed technologies for one's training and professional future.

The students were consulted using 60 questions about different aspects. In the first block, we obtained personal information (age, sex, and nationality), followed by information about the technologies they used or possessed, and finally, their perceptions and motivations regarding using devices and various technologies. The sample of 60 students (included both courses) included 26 males (mean age of 23.09 years with a standard deviation of 0.85) and 34 females (mean age of 22.35 years and standard deviation of 0.74). By graphically analyzing the average obtained responses related to technologies used and perceptions/motivations, we observed similar behaviors in both groups (Fig. 3).

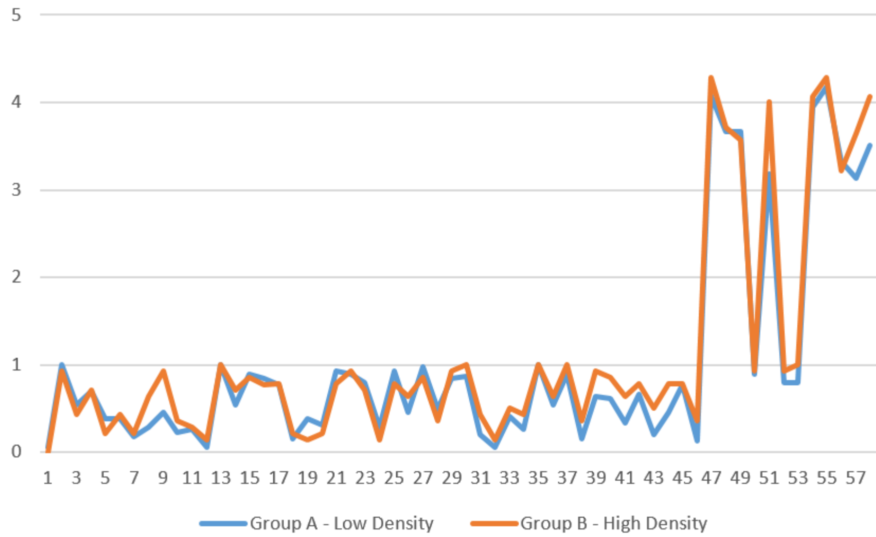

Figure 3. Comparison of groups' pre-course survey questions. X-Axis: number of question, Y-Axis: Likert scale from 0 to 5.

Fig. 3 illustrates the responses to two types of questions. In questions 1 to 46, subjects were asked about the use or possession of devices and technologies, with possible responses being 0 = "No use / Not applicable" and 1 = "Use / Applicable". In questions 47 to 60, a 5-point Likert scale was used to assess motivation and usefulness of various technologies and applications.

The pre-course survey mean scores were similar in the two groups. To estimate the probability that the groups were significantly similar, we used Student's t-test with the null hypothesis (H_0) of no differences in mean scores between the groups. The statistical significance (two-tailed) was 0.454, which exceeds the threshold of 0.05 and means that there is a very low probability that the groups differed in their skills and previous training (Table 1). The null hypothesis (of no significant differences between the groups) was therefore accepted.

Table 1 Student profile comparison between groups

PRE-TEST	t	Sig. (2-tailed)	Mean Diff.	Std. Error Difference
Equal variances assumed	0.634	0.454 > 0.05	-0.0543	0.1993

This initial survey revealed that 98.11% of the students had Smartphones, 50.94% had tablets, and 94% had laptops (with 34% using OSX, which is incompatible with many of the applications to be used). There was relatively low or declining ownership of other technologies, such as digital cameras (57%), MP3 players (26%), or game consoles (26.4%); these percentages were consistent with the results of previous studies (Fonseca, Redondo & Villagrasa, 2014). On the other hand, the rates of usability for both computers and mobile devices were very high (always above 90%), and the rates of jobs, searches and relations in the field of architectural visualization were between 60% and 85% of experience. These results allowed an evaluation of the first aspect of the proposal and an *a priori* statement that the working groups were prepared and digitally enabled to work with the proposed methods.

Second, we analyzed the responses related to the level of perceived usefulness and motivation regarding the educational use of visual technologies. The main indicators are shown in Fig. 4, which includes the average answers on a 5-point Likert scale (LOW answers are from the low-intensity course, and HIGH answers are from the high-intensity course described).

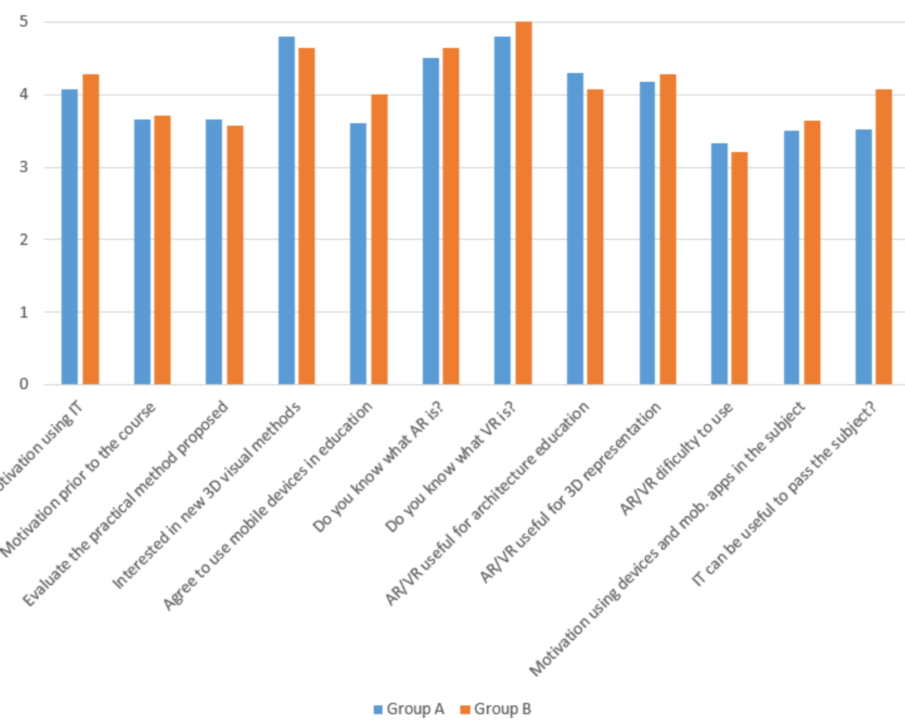

Figure 4. ICT knowledge and motivation (pre-test)

As Fig. 4 shows, the majority of indicators had high values (above 3.5/5); only the perceived difficulty of use/learning was below the average score, although perhaps this is not worrisome due to this being a negative variable. The results show that the group of students was quite homogeneous overall and demonstrated high interest in the use of technology in learning. A statistical comparison of the results (and was performed with the profile data) revealed no significant difference. The statistical significance (two-tailed) was 0.63, which was greater than the threshold of 0.05, meaning that there was no significant difference between the groups. The null hypothesis, that there were no significant differences between the groups, was validated.

4.2 Post-test

An evaluation of the average responses to the post-test (containing the same questions as the pre-test) revealed a series of differences between the groups that did not exist initially (Fig. 5).

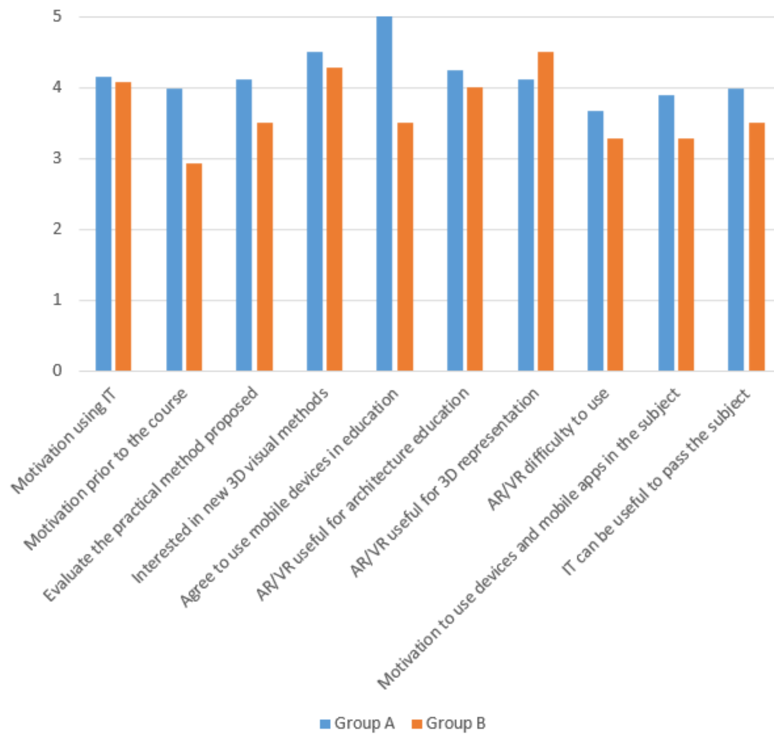

Figure 5. ICT Motivation (post-test)

Using the same comparative system as in the previous phase and with the null hypothesis (H_0) that there were no differences in mean scores between the groups, we found that the statistical significance (two-tailed) was 0.02618, below the standard threshold of significance of 0.05. This result indicates that there was a significant difference in the responses between the two groups, which implied that the experiment had changed student motivation and the overall perception of the use of technology in educational models in architecture.

To determine which group had undergone a significant *a priori* change in perception, we independently compared the results from each group before and after the experiment (Table 2).

Table 2 Paired two-sample t-test for means

	Pre-Test (Av.)	Post-Test (Av.)	t-Statistic	Critical t-Value	Statistical signif. (two-tailed)
Group A	3.86	4.16	-2.066	2.26	0.0687
Group B	3.95	3.68	2.715	2.26	0.0237

The statistical analysis revealed that group A had a slight (but nonsignificant) increase in the average evaluated response, whereas group B had a decrease that was below the significance threshold and thus could be considered significant as an overall value. An analysis of the factors with the greatest influence on this change (Fig. 6) revealed increases in both the perceived difficulty of working with the proposed systems and the sense of these systems' usefulness for 3D representation. All of the remaining questions, however, had lower values; of particular relevance were the stated motivation to complete the course (which decreased 21.1%), the usefulness of passing the course (with a decline of 14.1%) and agreement with the use of mobile devices in education (with a decline of 12.5%).

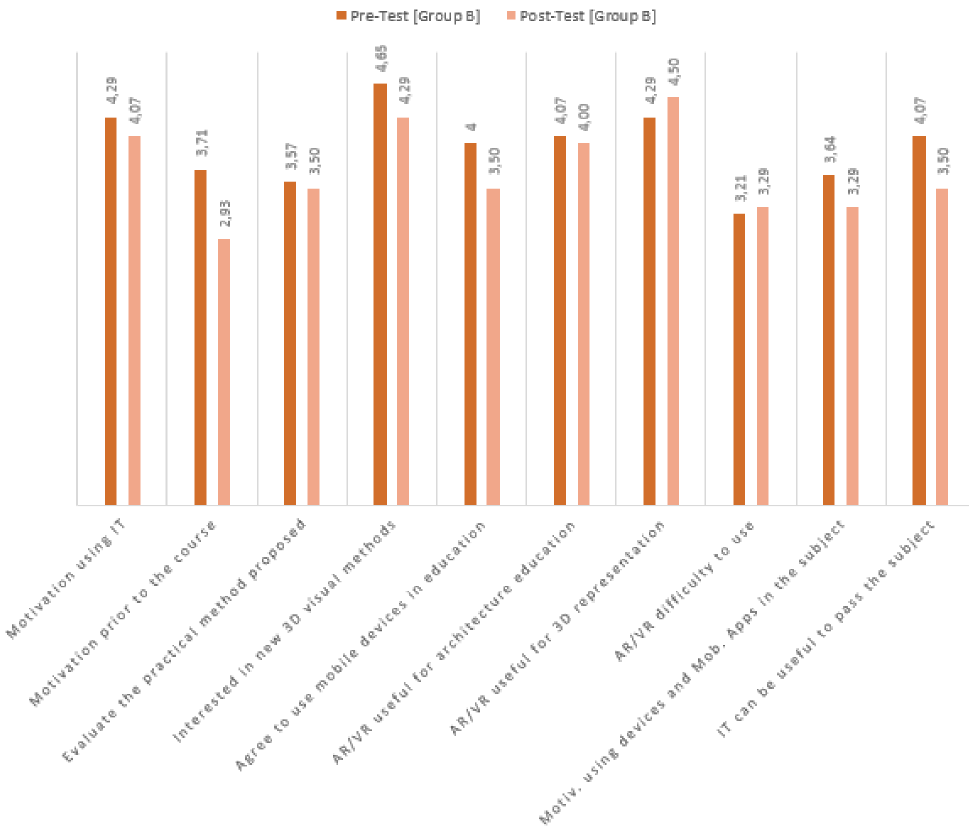

Figure 6. ICT Motivation group B (Pre/Post Comparison)

A detailed analysis of the three factors that underwent the largest decline in group B revealed that in group A, the following large increases were found after the completion of the course: motivation to complete the course rose 8.4%, usefulness of passing the course increased 13.6%, and agreement with the use of mobile devices in education increased to almost 40% acceptance (Fig. 7).

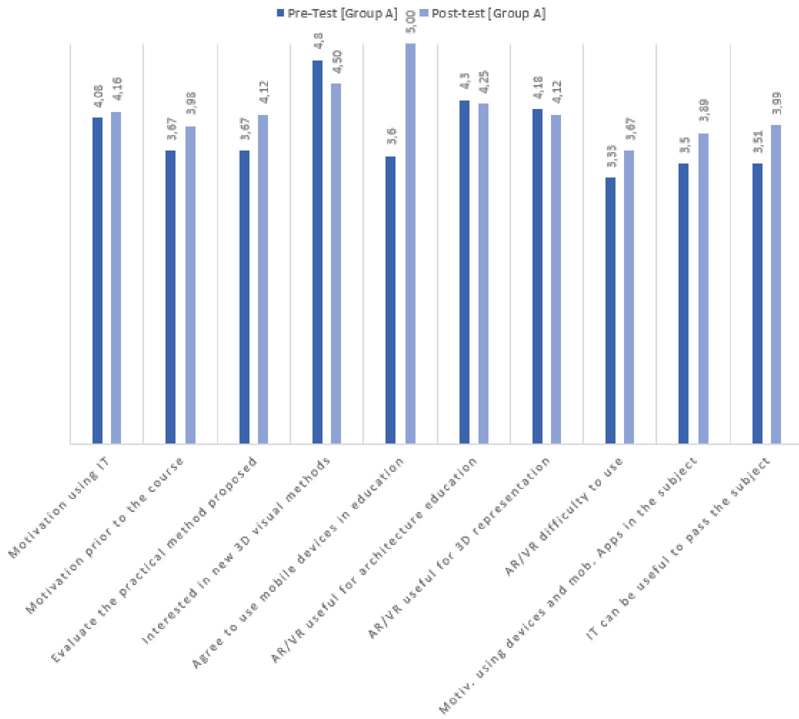

Figure 7. ICT Motivation group A (Pre/Post Comparison)

Based on these results and the verified hypothesis that the groups were initially homogeneous, we confirmed that a highly dense course affected students' motivation and final perception due to the amount of implemented applications. In this regard, the next set of questions asked in the post-test was designed to more specifically evaluate the perception of the method performed in each group. The results are presented in Fig. 8.

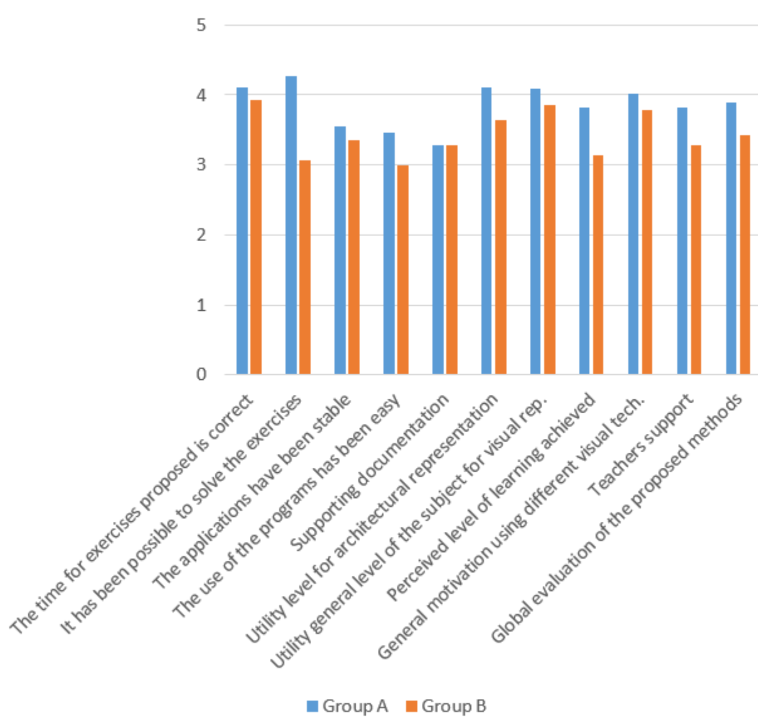

Figure 8. User Experience Evaluation

Fig. 8 clearly shows that for Group A (low density), the overall values for the design, implementation and satisfaction with the course were higher in all evaluated aspects, particularly the ability to solve the proposed exercises and the level of perceived learning gained. To assess whether this difference was significant, we used Student's t-test (as in the previous cases) with the null hypothesis (H_0) that there were differences in mean scores between the groups. The average for group A was 3.85 (SD: 0.09), whereas the average for group B was 3.43 (SD: 0.1). The critical t-value was 2.08, which the t-statistic clearly surpassed at 3.15. In conclusion, the statistical significance (two-tailed) was 0.0050, below the threshold of 0.05, indicating a high probability that the groups differed in their satisfaction with the implementation of the course. The null hypothesis (of significant differences between the groups) was therefore accepted.

Finally, students were asked to assess the different tools used and their level of satisfaction/experience with their use. Group A produced an average of 4.09 (SD: 0.79), and group B yielded 3.82 (SD: 1.04). Comparative statistics were performed to assess whether there was a significant difference; a value of 0.07 was found, above the threshold of 0.05. This result allowed us to generally state that the students had similar (and generally positive) opinions of the use of the proposed technologies, with no significant difference in the results and applications used.

4.3 Qualitative evaluation

Based on the results obtained through the completed quantitative surveys, it was necessary to analyze in greater detail the students in group B and their opinions of the designed proposal. To that effect, and in line with previous studies with mixed approaches, we completed a series of BLA interviews to specifically identify relevant aspects, both positive and negative, of the experience (Fonseca, Valls, Redondo & Villagrasa, 2015; Fonseca, Redondo & Villagrasa, 2015).

The BLA method works on positive and negative poles to define the strengths and weaknesses of a product. Once the element is obtained, the laddering technique is applied to define the relevant details of the product. The objective of a laddering interview is to uncover how product attributes, usage consequences, and personal values are linked in a person's mind. Conducting a BLA consists of three steps:

1. Elicitation of the elements: The implementation of the test starts with a blank template for the positive elements (strengths) and an identical template for the negative elements (weaknesses).
2. Marking of elements: Once the list of positive and negative elements is completed, the interviewer will ask the user to score each one from 0 (lowest possible level of satisfaction) to 10 (maximum level of satisfaction);
3. Element definition: The questions "Why is it a positive/negative element?" and "Why this score?" are asked. The answer must include a specific explanation of the exact characteristics that make the mentioned element a strength or weakness of the product.

From the results obtained, the next step was to polarize the elements based on two criteria:

1. Positive (Px) / Negative (Nx): The students were asked to differentiate the elements perceived as strong points of the experience that helped them to improve the type of work proposed as useful, satisfactory, or simply aesthetically functional. They then did the same for the negative aspects that did not facilitate work or simply need to be modified to be satisfactory or useful.
2. Common Elements (xC) / Particular (xP): Finally, the positive and negative elements that were repeated in the students' answers (common elements) and the responses that were given by only one of the students (particular elements) were separated according to the coding scheme shown.

In this type of analysis, the Positive/Negative Common (PC / NC) elements are the most representative because they are the most cited. Depending on the reference rate and its average obtained value, we can identify the most relevant elements. In group B, in which 10 surveys were completed (with a minimum of 6 being acceptable for this method), the main elements that were most commonly cited are shown in Table 3.

Table 3 Main BLA Results of Group B: Positive Common (PC) and Negative Common (NC) elements

	Description	Av. Score (Av)	Mention Index (MI)
1PC	Faculty	8.50	40%
2PC	New software explanations	6.75	40%
3PC	New methods for 3D representation	7.00	30%
4PC	Real utility	7.00	30%
1NC	Overview of several applications	4.50	70%
2NC	General organization of the subject	6.50	40%
3NC	Building modeling using photo-collage	5.00	20%

The main solutions and points of improvement were divided according to whether they were cited as improvements for positive elements or as solutions to negative indicators, as shown in Table 4. As for when proposing elements, we emphasized the common elements, namely those cited by at least 2 of the interviewed students.

Table 4 Proposed common improvements for PC and NC elements

	Description	Mention Index (MI)
1PCI for PC	More explanation	70%
2PCI for PC	Work with real cases	50%
3PCI for PC	Reduce applications to explain	30%
1PCI for NC	More time of explanation	70%
2PCI for NC	More organization of the subject	40%
3PCI for NC	Explain more 3ds Max in previous courses	30%
4PCI for NC	Reduce the number of applications	30%

The analysis of these results revealed that the design of the course clearly produced stress in the students. The high numbers of applications and explained techniques were reported as being of interest given their real utility (with reference indices between 30% and 40%), but with far from high reference rates (which are usually fixed at 70%) and with optimal averages (above 8/10). This superficial explanation was reflected as a clearly negative element (referenced by 70% of the students), and the problem was confirmed through the solutions proposed: a longer explanation time was again the most notable feature of the positive and negative commentaries (doubly indicated with a reference rate of 70%).

Another major aspect that was reflected and influenced the decline found in the post-test was the organization of the course and its relationship to previous courses. There is clearly a need to consider restructuring previous courses to include more extensive explanations of software such as 3ds Max, which could enable better time management in these highly dense proposals.

In conclusion, it is clear that prior design is of vital importance to this type of proposal, and the time dedicated to each system is critical because an application that could be initially interesting ultimately takes time away from other, previously known ones that students ultimately consider to be highly important (as reflected in the case of photo-collage, with too much time devoted to its explanation or given importance, time that perhaps would have been better spent reinforcing the 3DMAX explanation). Undoubtedly, it was demonstrated that this mixed approach allowed us to more precisely identify positive and negative elements of a working model. We depended on the users (in this, case students) to show where it is necessary to strengthen the experience to improve the results in future iterations of the method.

Using the same system of work, we interviewed 8 randomly selected students from course A; the results obtained from the BLA are presented in Table 5.

Table 5 Main BLA Results of Group A: Positive Common (PC) and Negative Common (NC) elements

	Description	Av. Score (Av)	Mention Index (MI)
1PC	Use of virtual/augmented reality in exercises	9.00	90%
2PC	Use of digital technologies for 3D architectural representation	8.00	80%
3PC	Creativity assignments	9.50	60%
4PC	Gamification and collaboration techniques	7.75	50%
1NC	Little time for 3D learning	4.00	90%
2NC	Many applications explained	5.00	40%
2NC	Points & Badges of the gamification	6.00	30%
3NC	Group grades vs. Individual grades	5.00	30%

The grouped proposals that mentioned common improvements can be seen in Table 6:

Table 6 Proposed Common Improvements

	Description	Mention Index (MI)
1PCI	Web with tutorials	60%
2PCI	Unified systems for 3D modeling and gamification	60%
3PCI	More documentation of the evaluation system	40%
4PCI	Smaller groups and lower student/professor ratio	30%

Above the rates of mention that we considered significant, we find both positive elements (90% use of AR/VR and 80% general use of 3D technologies) and negative elements (little time explaining technologies, with a 90% rate of mention). However, we again find a “complaint” about the number of applications and/or explained systems, as happened in group B. In this case, the majority of proposals were linked to provide greater documentation and examples of the systems used, but they continued to reflect attitudes toward unifying systems in place of using various applications.

5. CONCLUSIONS

This paper presents the design of two courses focused on studies of architecture with the essential use of several advanced representation technologies. Both courses had a duration of one semester; the essential difference between them was the type and variety of technologies used. The results presented show that the two groups had similar technological profiles (their differences were not statistically significant), which confirms the viability of the proposal and the comparison of the results. However, the results of the assessment of the different degrees of initial motivation between the two groups must be examined to evaluate the relationship between motivation and technological behavior.

Once the course was completed and the results of the post-test had been analyzed, it was clear that the adaptation of students to a highly dense course with a superficial explanation of the applications was not the desired optimum. Course B, which focused on demonstrating that it is not necessary to understand applications in depth to manage a professional workflow, resulted in a perception by the students of insufficient time and the need for deeper explanations of certain aspects. Additionally, the qualitative study identified the exact areas where the students would prefer either reduced or eliminated explanation time, or the opposite – contents identified to be of such importance that they should have been addressed more extensively in previous courses. This resulted in technological behavior that significantly diminished their initial motivation and that we identified as the previously known concept of technological stress.

On the contrary, the most traditional methodology, based on a smaller number of applications with much slower and deliberate explanations, demonstrated greater effectiveness as perceived by the students, increasing their final motivation to use technologies in the educational environment. Nonetheless, even with the much slower and more deliberate system of explaining different technologies, it was detected that the students did not feel comfortable. According to the qualitative comments, a certain stress was still perceived when the number of applications in a semester exceeded two, regardless of the student's digital level.

The digital training initially assumed the students to be digital natives, and the presumption that this training could be better adapted to a more rapid and superficial explanation of a high number of technologies based on that profile was not validated. The results showed that the students were more comfortable and preferred slow, deliberate, and in-depth explanations of a few systems, an approach that requires the correct selection of the applications that they should study. If that approach is chosen for future courses, it seems vital to be able to demonstrate why the explained applications are used by providing real cases and real use because it has been demonstrated that students demand examples and actual cases of applying technologies.

In conclusion and based on the two hypotheses defined in the introduction, on the one hand, it was not validated that the students as digital users adapted better to a high density of technological content in the educational environment; this approach generated stress, which resulted in a loss of motivation to use the explained systems. On the other hand, the claim that the use of advanced visualization technology improves student motivation was validated, but only in part. However, it is important to set a correct limit on the number of explained systems so that this motivation does not diminish. We can conclude that although the current students have regularly used all types of technology and digital systems, when working or using them professionally, they have a very similar level to our students from a few years ago, including knowing which systems only involve habits that are inappropriate and usually difficult to correct.

Clearly, the obtained results suggest two lines of future study: 1) the changes to the methods proposed by the students should be adapted, and the extent to which these changes improve the designed experiences should be evaluated; and 2) the correlation of the assessment of the experiments with academic outcomes should be studied. As we demonstrated in other experiences cited above, motivation tends to be highly correlated with academic improvement. Although we might expect the same from our case study, we were unable to conduct this study due to not having previous grades available in one of the cases, different groups not having been studied, and not having a control group. For these reasons, our immediately future experiments will be related with the study of the correlation between the academic results and the variables studied in our educational proposals. In addition, we will focus our future proposals in the application of ICTs on mobile educational case studies centered to explain the 3D space of cultural places, a basic skill and competence associated with the Architectural, Urban and Landscape studies.

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