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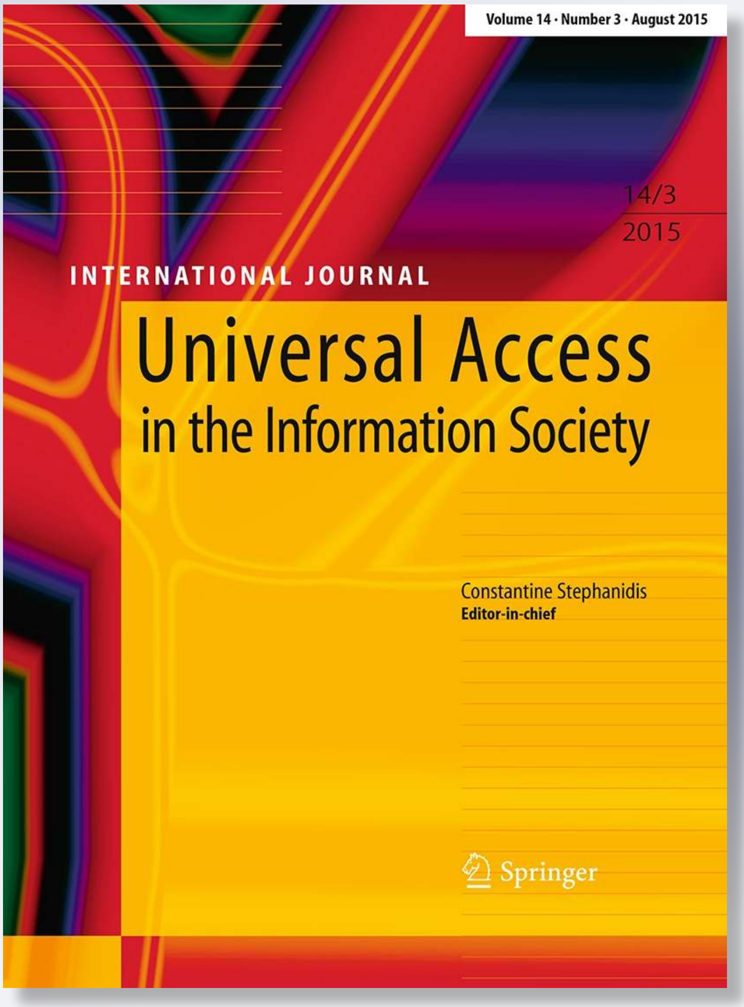
Universal Access in the Information Society
International Journal

ISSN 1615-5289
Volume 14
Number 3

Univ Access Inf Soc (2015) 14:311-332
DOI 10.1007/s10209-014-0361-4



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LONG PAPER

Mixed-methods research: a new approach to evaluating the motivation and satisfaction of university students using advanced visual technologies

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Published online: 24 July 2014

Abstract A mixed-methods study evaluating the motivation and satisfaction of Architecture degree students using interactive visualization methods is presented in this paper. New technology implementations in the teaching field have been largely extended to all types of levels and educational frameworks. However, these innovations require approval validation and evaluation by the final users, the students. In this paper, the advantages and disadvantages of applying mixed evaluation technology are discussed in a case study of the use of interactive and collaborative tools for the visualization of 3D architectonical models. The main objective was to evaluate Architecture and Building Science students' the motivation to use and satisfaction with this type of technology and to obtain adequate feedback that allows for the optimization of this type of experiment in future iterations.

Keywords User experience · Mixed method research · Augmented reality · Teaching innovation · Motivation · Satisfaction

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1 Introduction

The current paper is based on three main pillars. The first pillar focuses on teaching innovations within the university framework that cultivate higher motivation and satisfaction in students. The second pillar concerns how to implement such an innovation; the paper proposes the utilization of determinate tools of the so-called information technologies (IT), so that students, as "digital natives", will be more comfortable in the learning experience [1]. Finally, the study employs a mixed analysis method to concretely obtain the most relevant aspects of the experience that should be improved both in future interactions and in any new technological implementations within a teaching framework [2].

While the three pillars mentioned above are not innovations themselves, their integration into an experiment gives them a clearly innovative character, and there are few similar examples today [3, 4]. In addition, the design of the study focuses on the university level, specifically Architecture studies and the complementary areas of Building Engineering (the name of the degree is currently under revision, as Sciences and Building Technologies is the degree accepted at the governmental level) and Design, where spatial comprehension is very important and IT (information technologies) elements are very helpful. Thus, this work is both novel and justified.

Today, the incorporation of technology into classrooms is a fact [5], though one cannot affirm that using technology will lead to an increase in the motivation, satisfaction, or academic achievement of students [6]. As will be shown in Sect. 3, technology must be incorporated into teaching in a controlled manner; there are some risks that need to be controlled before one can improve not only the curriculum but also student skills and knowledge. Academic fields are reticent about incorporating technologies associated with leisure (such as mobile devices). With technology, the professor must be trained and capable of providing full-time support to students: He or she must be capable of offering a good and precise explanation of the practice and methodology, must correctly select the applications, and must provide clear final objectives. Previous studies describe "critical mistakes" in the implementation of educational technology—mistakes that can generate negative perceptions among the students and which need to be avoided [7–10].

The need of and justification for incorporating IT into the educational process are particularly relevant, and they are described in the main roles of the *European Higher Education Area* (EHEA), which runs the university studies of member countries, including Spain, where this project was undertaken [11].

It is common to find studies focused on all teaching types and levels that evaluate the incorporation of technology and technological elements into teaching; the most common examples are the use of computers in the classroom and the use of digital content for online training [12, 13]. Usually, teachers design educational experiments based on the technology that is available at their college or that is accessible to their students, assuming (based on their experience) that the use of new IT will be possible and beneficial to students.

However, it must be emphasized that the above-mentioned quantitative studies have small sample sizes (quantitative studies are focused on defined variables, which are better described with a large sample and a large number of respondents), and they lack clear questions to identify the degree of information that two or more variables could provide (descriptive, predictive, or casual questions that differentiates research problems.). These studies are typical examples of studies that generate incomplete data [14, 15], lack detail, and are missing variables because of the initial design flaws.

This lack of accuracy is due to the teachers' inadequate preselection of questions; these questions focus on evaluating objectives, without taking into account previous statistical assumptions, sample size, inappropriate treatment of the data, and the possible types of errors that could modify or influence the students' answers [16]. The possibility of biased results provides a starting point, previously used in related academic fields [17], allowing to approach the experiment with a mixed methodology and benefit from different data analysis methods. Using complementary qualitative research, it is possible to obtain new variables to study in future iterations and more detail for the quantitative data. Meanwhile, thanks to the quantitative data, it is possible to minimize the primary problems of the qualitative research: subjectivity and no generalization [18].

Another factor that has limited studies in some teaching areas is tradition, while in fields such as medicine, ethnography, sociology, and economics, it would not be correct to present data without properly defining the sample. In other educational frameworks (such as law, engineering, or artistic education, which includes architecture), studies relying on user feedback are less common, either because of the study methodology, the assumption that user feedback is of little utility, or the lack of time for collecting such information.

For all these reasons, and because Spanish universities are currently facing a deep social crisis in which the number of university students in Spain and in other countries where higher education is costly is in decline, it is necessary to motivate students more. The goal is to optimize students' understanding of academic subjects and the way in which they are taught. The use of "friendly technology" that is successfully adapted to the specific needs of each subject must help students better adapt to education at the university level and to the new sociocultural context in which IT has a massive presence.

In this paper, a mixed-methods study evaluating the motivation, satisfaction, and academic performance of degree students is presented. The methodology is both quantitative (through a structured test) and qualitative (using the bipolar laddering (BLA) [19]), and it is based on the use of augmented reality (AR) to present, visualize, and discuss an architecture project realized using CAD tools (computer-assisted design). Whether this type of exercise can help students understand and improve their 3D skills will be evaluated. As a starting point, students will work on their assignment and compare two ways of doing so: the traditional system that uses printed plans and conceptual mock-ups and the method of using 3D interactive model visualizations on mobile devices with different generation techniques.

The working hypothesis to be confirmed is whether students who invest less time in the assignment will obtain better academic results because they are more motivated and satisfied than they are under the classic working system, taking into consideration that today, the architectonic teaching field is based almost 100 % on digital drawings and photomontages of 2D and 3D images. The secondary objective was to ascertain through a mixed-methods analysis of quantitative and qualitative data the most positive and negative aspects of the experience, with the aim of adapting the implementation method in future iterations and for other subjects.

Section 3 of this paper includes an overview of academic performance using AR and discusses how this type of technology can improve students' 3D spatial skills. The main features of quantitative, qualitative, mixed research, and the user experience (UX) concepts applied in the educational framework are described in Sect. 4. In addition, the study methodology is described. Section 5 includes the research results, which are discussed in Sect. 6.

2 Mobile technology, education, and their relationship with universal access and design for all

Simplifying the description of our society, one would affirm that there are two primary frameworks: real and virtual. In the real field, the architect is the principal character who models human spaces together with several others professionals: civil engineers, factory designers, plant engineers, structural engineers, etc. In recent years, the designs and projects in the field of architecture have reflected an evolution toward more sustainable construction adapted for people and their environments. This shift has increased the preliminary studies of the characteristics and requirements of sustainable architecture projects and designs. For these reasons, all studies are usually conducted in two parts: the project itself (infrastructure, security, etc.) and the user (typology, access, special needs for disabilities, etc.).

In the virtual framework, uncounted resources have been dedicated over the last several decades to improve and generate new models and methods for accessing content (rules and recommendations), thereby adapting those contents to all types of users and devices [20]. These efforts are dynamic and constantly changing, especially considering the constant technological revolution that continuously transforms these devices and their capabilities.

Substantial effort is being made to adapt the content on mobile devices because their popularization and the progressive lowering of their cost have given them a significant presence in society. In particular, aspects such as security [21], and adaptation and communication with users of advanced age [22], or with disabilities [23], are perhaps the most developed work within Design or Multimedia studies. These aspects are the main disciplines in the effort to generate applications that are accessible to all types of users, with customizable and usable interaction adapted to the basic navigation rules [20].

In the architectural context, the core of the work presented here, many efforts are made to improve the methods for visualizing, exposing, and discussing architectural projects, especially in 3D [24]. The classic methods based on printed plans and physical models are expensive and poorly adapted to changes in the characteristics of users. For instance, performing a plane requires suitable space and expensive equipment, in the same way that a physical model requires materials and a slow production system, making this method expensive and generally not suitable for people with disabilities. A printed plan that requires different system units or any other modification generates a slow workflow and creates clear difficulties when adapting to a fast-changing society.

For the previously mentioned reasons, digital workflows have improved the described problems, and university students (digital natives) are often able to achieve better methods than many experienced professionals who are unable to use the new technologies. The visualization and discussion of an architectural project in 3D using mobile devices generate a faster workflow, allow students to adapt their design to the real scale of construction, and allow them to easily modify and customize the project for little or no cost.

Previous studies have discussed the use of 3D visualization in general [25], and specifically AR, for the visualization of architectural design to adapt designs to the environment, avoiding problems of scaling, lighting, and texturing [26–29]. In addition, through these technologies, a user outside of the professional sector can obtain more enjoyable access to all types of information, such as tourist applications [30].

Complementing the current developments, and especially useful in the field of accessibility and Design for All, are geo-referenced applications. These applications utilize the user's position, obtained through their personal mobile device, to provide extended information that is customized for all services [23]. In the design of any project, the architect must be aware of its accessibility once built. The project should be accessible and adaptable for the users in their digital formats, enabling any user interaction [31]. Using the geo-referenced capability of these devices, systems with audio description and AR, all types of users (experts/non-experts, with/without disabilities, local, and foreigner) could feasibly to obtain extended information from any architectural project, both at the user level (author, year, main topics, etc.) and an advanced level (materials, type of construction, layers, electrical installations, etc.).

To conclude this section, it is reaffirmed that the ideological basis of the project is to evaluate how the student adapts to the use and design of the various visualization methods that are accessible to any user: in person using 2D printed layouts, virtually by posting interactive models on the Internet, or, finally, using AR visualization for a combined interaction. To the students from the first course, the importance of generating universally accessible content is introduced, allowing them to train their skills so that in the future, they can create more accessible designs for all types of users and environments.

3 IT in education. 3D models and AR visualization

The incorporation of IT in today's society has shaped new forms of interaction at all levels, from communication to entertainment to training. However, carrying out new learning experiences using IT is not an easy process that is always successful. In fact, it is easy to find previous studies that have documented the problems and failures in processes of implementing IT in education [32–34].

The main problems in executing IT in education (usually using computers in the classroom or using online content) include the lack of computers, poor connectivity, long training periods and hefty investments required by certain tools, the belief that IT is just for leisure and entertainment, and the lack of support from both the institution and the government [33, 35, 36]. For these reasons, it is easy to find all kinds of recent research focused on discovering and implementing "good teaching practices" [37, 38]. Under this nomenclature, complex and heterogeneous ways can be found (which in many cases are not reusable from one domain to another) of designing content, teaching methodologies, and efficient uses of technological elements [39, 40], in order to ensure successful experiences (that generate improved curricula) that motivate and satisfy students.

In the following, some of the main models and methodologies that define "good teaching practices" in using technology will be reviewed so that the proposed method can be adapted to these recommendations.

3.1 Good education practices in using IT

IT is a set of tools and applications that allow the incorporation and strengthening of new educational strategies, many of which have been defined in new teaching frameworks during the last two decades [5, 41]. The interest, need, and urgency to implement new technologies in education and in universities in particular are relatively new [39].

However, technological innovation, which is intended to improve the student learning process (with studies that link the use of IT with improved academic performance [36]), must be capable of providing support to address difficulties for students while using and interacting with technological elements.

To incorporate an IT-based methodology into a specific teaching environment, some recommendations for avoiding student rejection must be considered (so-called good educational practices that are primarily focused on virtual rooms, e-learning, and semi-present teaching [42, 43]). From the specific characteristics that shape these practices, four points can be extrapolated, as indicated by the following principal objectives:

- Promotion of professor–student relationships, allowing for a more effective feedback process
- Dynamic development among students, which is made possible by collaborative techniques
- Contribution to better task realization by heterogeneous learning methods, meeting high expectations
- Applying teaching/learning methods based on teaching innovation and new IT technologies.

These new concepts generate a new type of student, who is much more dynamic and capable of having a more participatory role in the educational process (who could be called a "3.0 Student," similar to the evolution of Web 2.0 to 3.0). In accordance with Massy and Zemsky [44], any methodology that promotes the inclusion of IT in teaching must have the following objectives:

- Personal production help: applications that allow both the professors and students to carry out tasks faster and more efficiently (e.g., calculation sheets or text processers, draw programs);
- Content improvement: the use of tools that allow for the notification and modification of content rapidly and efficiently (e.g., e-mail, digital content, video, multimedia resources) without changing the basic teaching method;
- Paradigm change: At this level, the teacher reconfigures the teaching activity and learning activities to utilize the new incorporated technologies.

Examples of educational methodologies that have implemented the first two objectives are common, though it is difficult to find examples that incorporate the third objective and the practices where the third objective is implemented. Most of the solutions involve basic tools and derive applications of an Internet connection [45].

The technological pedagogical content knowledge model (TPACK [46]) is probably already used by many teachers unconsciously. TPACK (which extends Shulman's idea of pedagogical content knowledge [47]) describes how an activity that requires technology must be integrated adequately into the classroom by connecting three knowledge fields: curricular, pedagogical, and technological (see Fig. 1):

The model is based on a current teaching context characterized by a high degree of complexity and great dynamism, making necessary the integration of multiple knowledge components [48]:

- The curriculum, which can be understood as the theme or content selected for technological implementation, including the objectives to be achieved and the possible necessity of prior knowledge;
- The pedagogy, which includes the activities and their delivery, the teacher's and students' roles, and the evaluation system;

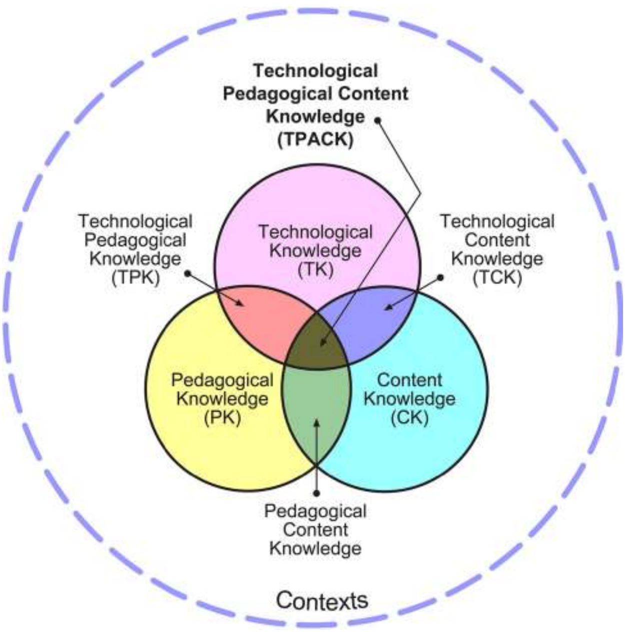


Fig. 1 The TPACK Framework and its Knowledge Components. Reproduced with permission from the publisher, ©2012 by tpack.org

- The technical component, including the training necessary for using the technological resources, the selection criteria for the technological devices, and the proposed uses for the technology.

If in the process of designing an educational experience, appropriate individual aspects of the main areas are included, one may be closer to redefining and integrating any type of technology into teaching activities, moving away from classic approaches that have been used in current and past technology integration efforts [49]:

- Software-focused initiatives
- Demonstrations of sample resources, lessons, and projects
- Technology-based educational reform efforts
- Structured/standardized professional development workshops or courses
- Technology-focused teacher education courses

These approaches tend to initiate and organize their efforts according to the educational technologies being used (and preferred by the teacher or the institution) rather than the students' learning needs, which is exactly the opposite of the desired approach in which the user is a central element of the experience, due to the user's technological profile, motivation for experiencing new pedagogical methods, and evaluation of both the quantitative and qualitative aspects of the experience. This approach provides primordial data about new models of technological implementation in the teaching field.

3.2 3D virtual visualization using AR

In architecture and building education, the visual component is one of the most relevant aspects for students; hence, it is important for students to be able to interpret information visually [41, 50]. Spatial information is represented in a number of ways, ranging from traditional methods that include printed plans and physical models to modern methods that include digital printed plans and tridimensional models, which allow a greater level of detail and the ability to navigate and actualize potential changes instantaneously. These different visualization methods allow both students and professionals to work collaboratively and communicate their ideas about the space and the project more efficiently [51].

Both CAD and BIM (building information modeling) have positioned the AEC (Architecture, Engineering and Construction) sector as one of the main consumers of 3D technology for the management, design, and display of any item related to the architectural project. However, these technologies have not been extended to other devices, particularly in the case of mobile technologies. For example, companies such as Autodesk® (San Rafael, CA, USA), one of the largest software manufacturers for architecture, already had solutions for both 2D and 3D visualizations in mobile environments in the mid-1990s (OnSite®); however, the lack of appropriate devices and connections considerably impeded the use of these technologies. The excessive size of files along with the lack of affordable, high-performing mobile devices kept the ubiquitous CAD/BIM models far from classrooms and even from some professional sectors.

In the last decade, with the emergence of smartphones and tablets with the latest generation of processors, the reduced cost of devices and services, the increase in connection speeds, and, in particular, the popularization of Wi-Fi networks, there has been a real possibility of providing quality anywhere. It is during this period that concepts such as QR-Code (Quick Response Code, created by the Japanese company Denso Wave, in 1994) and AR, both of which involve the use of a camera as well as an informatics processor, were popularized, while the first references to this kind of technology date from much earlier (the term "augmented reality" has been attributed to Tom Caudell, a former Boeing researcher in 1990, but the most clear and formal work is found in [52]).

Currently, in Spain, 43 % of users that connect to the Internet do so from a smartphone (210 % more than in 2011). Spain is the European country with the highest usage of this type of mobile phones (63.2 % of mobile phone users have smartphones; the United Kingdom is second with 62.3 % of users; and France third with 51.4 %) [53]. The navigation functions that smartphones offer, as well as their high performance in visual content exchange between users, have positioned them as indispensable devices both professionally and socially, especially among young people and pre-college and university students (as the current study's data will show almost 100 % of users in classrooms classroom have smartphones, opening the possibility of implementing educational experiences on these device, as the proposed one in this paper).

However, as is typical with almost all technologies, adapting content tends to affect interaction and usability on the one hand and appreciation of the utility of the technology on the other, which can in turn lead to loss of motivation and satisfaction with the experience. The elevated number of applications and formats makes it difficult to work with a single line of products or manufacturers [54] and renders it necessary to exchange files between different lines of products and formats. Using different applications directly impacts the methodological design of any educational experiment, because it is necessary to plan for more time in order to explain the applications, reducing time for other topics directly related to the predefined agenda.

For example, currently in Spain, Autodesk® applications such as AutoCAD®, 3DS®, and Revit Architecture® are the CAD/BIM products most frequently used by both professional architects and architecture students. For RA, Juanio®, Layar®, and Augment®, compatible with iOS and Android, are probably the most-used free applications. A problem arises when one needs to convert CAD/BIM models to the RA display system because the formats are not compatible; new intermediate applications such as Google Sketchup© (paid versions) allow the generation of compatible models between all of the working solutions.

Previous studies that evaluated the use of IT in teaching activities related to architecture/construction was focused on the use of whiteboards, interactive books, social media, and other resources related to the visualization of 3D models, buildings, and spaces in architecture education [55, 56]. More recently, immersive technologies have been used in virtual and AR worlds, and their usefulness has been assessed by a number of international projects [57–60]. These experiences demonstrated the vast potential of this technology; however, in education, AR might be considered a new tool, and further studies are necessary, with particular focus on the user experience and learning process [41].

4 Mixed-methods research and UX in an educational framework

4.1 Quantitative, qualitative, and mixed methods

Quantitative and qualitative approaches have historically been the main methods of scientific research. Currently, a hybrid approach to experimental methodology has emerged that takes a more holistic view of methodological problems: the mixed-methods research approach. This model is based on a pragmatic paradigm that contemplates the possibility of combining quantitative and qualitative methods to achieve complementary results. The value of research lays not so much in the epistemology of the method but in its effectiveness [61].

On the one hand, quantitative research focuses on analyzing the degree of association between quantified variables, as promulgated by logical positivism; therefore, this method requires induction to understand the results of the investigation. Because this paradigm considers that phenomena can be reduced to empirical indicators that represent reality, quantitative methods are considered objective [62, 63].

On the other hand, qualitative research focuses on detecting and processing intentions. Unlike quantitative methods, qualitative methods require deduction to interpret results. The qualitative approach is subjective, as it is assumed that reality is multifaceted and not reducible to a universal indicator [64].

Qualitative methods have been traditionally linked to the social sciences because of their association with human factors, although the mixed approach proposes integration of quantitative and qualitative approaches with the goal of facilitating the interpretation of experimental results. This combination of quantitative and qualitative experimental designs leads to a wider variety of results when dealing with human factors that include both numerical results and the basis for these results. The possibility to work with both types of information simultaneously in a single study is a great advantage to a research team: Multidimensional outcomes make it much easier to propose solutions and further research steps in a given field of study.

4.2 UX techniques for pedagogical purposes

User research techniques have been historically related to the HCI field. The user approach in this discipline is mainly focused on the study of behavioral goals in work settings. In consequence, the task became the pivotal point of user-centered analysis and evaluation techniques (e.g., usability testing [65]). Facing the mechanical vision of HCI user's research, Don Norman [66] popularized the term User Experience to include the feelings and meaningful aspects of user interaction with machines and services. Since then, many studies have enriched this trend working on concepts and new branches of User Experience as design and emotion, [67], "Funology" [68], "Hedonomics" [69], or most recently "Gamification" [70].

The current methods in UX do not necessarily include the end user to participate in the creative process of the product. Most of them are guides of imagination exercises to be more emphatic with the user in concrete scenarios as cognitive walkthroughs [71], or user persons [72]. On the other hand, there are also qualitative methods far from usability standards which allow obtaining subjective information from users themselves, such as contextual design [73] or diary methods [74].

4.3 Methodological proposal: case study: 3D-AR building visualization for architecture students

Research into users, contexts, and cultures has increasingly taken place in product development cycles. Yet, this is structured by the objectivist assumption that users are not creative and do not know what they want [75]. The methodological approach of this work let the end users, in this case students of first course of "Architecture" and "Building Sciences and Technologies" degrees of La Salle Campus Barcelona, Ramon Llull University, participate in the definition of the final product, in this case a pedagogical proposal, through methods that allowed them to be creative during the design process.

The empirical vision of user research does not involve the intended user in the conceptual design process. Few user research methods come from experimental psychology and ethnography and are focused on the observation and analysis of user behavior. In this project, the intention was to combine qualitative and quantitative methods in a mixed methodology to analyze the complex area of individual user experiences by not only observing their behavior but also defining the causes of it.

Through qualitative methods, the goal was to explore users' desires, needs, and goals when learning about informatics tools that they would use to present 3D projects in their future work. The methods that were applied in this work are a combination of objective methods based on empirical models and subjective data-gathering techniques inspired by constructivist psychology interviewing techniques.

Thus, the active participation of end users can be a reliable guide for creating a proposal to enhance creativity in each end user's field. Turning to Fig. 2, one can observe the methodological process that was followed.

This project is methodologically based on the "user research" that has been applied to the field of UX. Mixed methods have been regularly applied in this discipline to achieve pragmatic results in the assessment and improvement of the relationship between subjects and students and RA technologies for architecture. UX techniques are geared toward the design of products and services, which is an unorthodox way to consider the user–product relationship. In this particular case, the student is considered to be the user and the new method is considered to be the product or service. In this way, the experience is framed as the implementation of a series of tasks that allow for the application of techniques for obtaining and systematizing data to assess student experiences and identify product improvements.

This study seeks to come closer to depicting the mental model of a student, or the cognitive scenario in which the elements are represented as part of the environment, tasks, and principles that govern its operation and relations [76]. The student, at the end of the experience, will be able to implement new methods for sharing information using ubiquitous systems such as smart devices, which will become increasingly widespread in future professional work [77, 78].

According to Norman [79], there is always a difference between the mental model of the user and the mental model of the designer in defining the handling and characteristics of the object or service being designed. This divergence causes deficiencies that always lead to an upset or under-utilization on the part of the user. For this reason, the developer must understand the mental model of the users or potential users. Investigating this divergence between the experience of the students and intentions of the designer makes it possible to evaluate the impact of including RA tools in the experience and to identify points of improvement for future iterations.

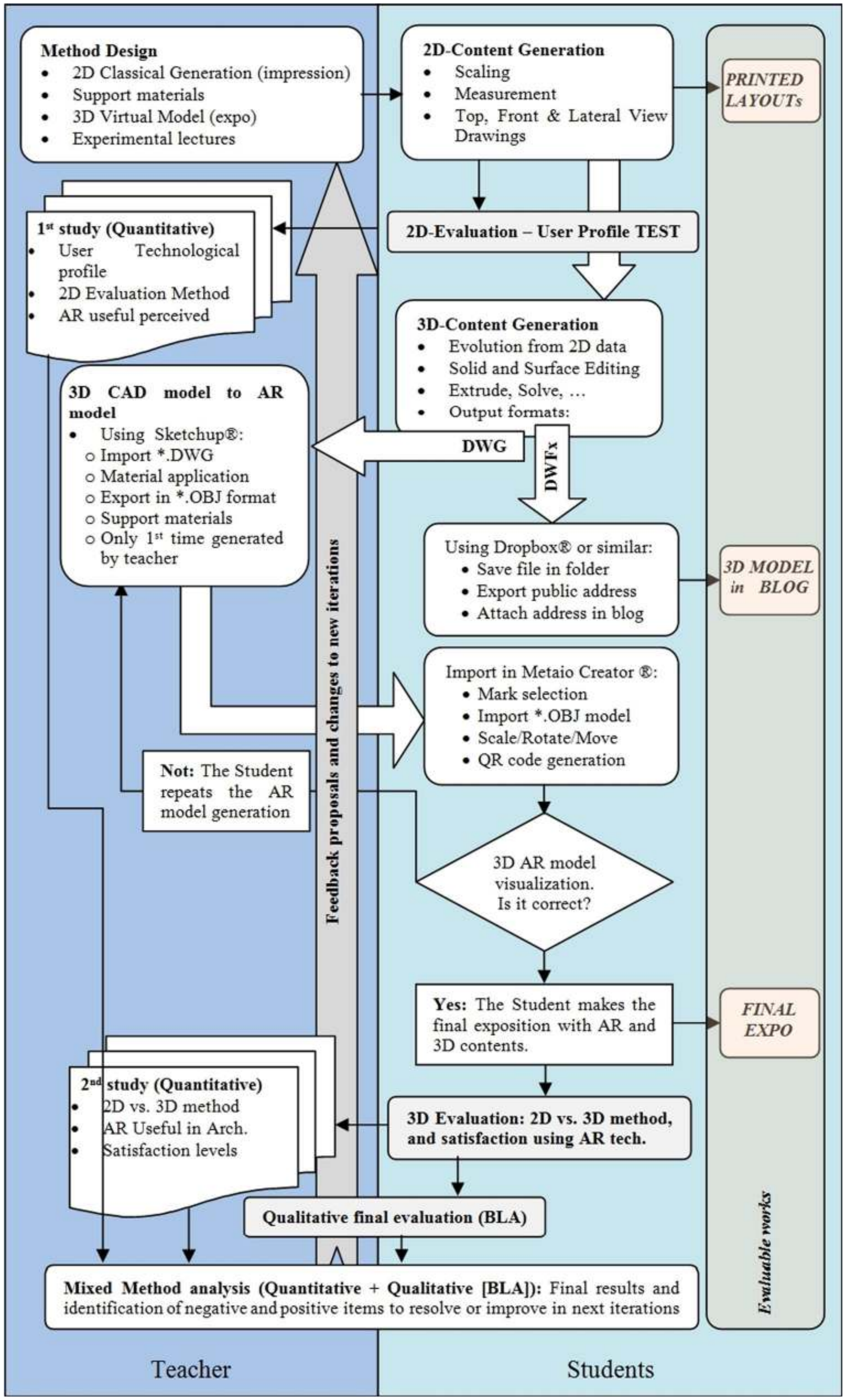
The project was modeled by the CAD/BIM Group of the Architecture Department of La Salle, Ramon Llull University. The study was performed during the 2012–2013 academic year with students in their first year of an Architecture and Building Engineering degree. The experimental framework was completed in the course "Informatics Tools I" a six-ECTS-credit course that is taught semi-annually.

The course consists of 4 h of lectures, spread over two weekly sessions of 2 h each, and an additional 3 h of practical sessions. The students also have weekly 1-h personal tutorials to address their doubts and solve practical problems.

The basic objective of the course was to provide students with basic skills in architectural interpretation and reproduction in both 2D and 3D. The secondary objectives were to enable students to print 2D and 3D reproductions, as well as to explore methods of interactive visualization, primarily through the publication of personal blogs and the display of models with RA at the end of the course. A total of 48 students participated in the study (18 females and 30 males, mean age = 19.54 years, standard deviation (SD) = 2.15).

As shown in the proposed work scheme, there is a constant interaction between the student and the professor throughout the process. Of particular relevance is the

Fig. 2 General scheme of the methodological process



feedback process based on data provided by the students, which will lead to active modification of the methodology for future iterations of the process.

At the same time, to achieve the most optimal integration of the student, the course starts at a basic level to allow the representation of any type of architectural project, based on the requirements of architectural analysis and the fundamentals of the projects required during the first 2 years of the degree program.

During the first phase, the methodological proposal focuses on new techniques for enabling the publication and interactive visualization of 3D models. The success of the exercises in the second phase will define the success of the proposal. In addition, an increase in student spatial abilities and motivation to use such techniques will be evaluated.

Finally, because this class is taught on a yearly basis, and in the 2011–2012 academic year, the authors began designing the teaching experience based on multiple uses of visualization tools [80], certain questions have already been asked, which will help to compare the evolution of the student profile in the past two academic years.

4.4 Experimental design

The first step of the process was the selection of the architectural project to carry out. Usually, the projects chosen for the experiment were preselected by the academic coordinators and the university studies' board of directors. The projects are generally local projects that allow for a better approach and knowledge of each case by the student: public buildings or projects designed by architects that are part of the university professorship.

In the academic year of reference (2012–2013), "Casa B-10" (1996–2001) by the architect Jaume Bach and "Casa A-M" (1999–2001) by the architect Elena Mateu were selected. These projects present diverse information that is available in books or present in monographs in the university library, with additional information from online sources, which allows the realization of all types of exercises proposed.

In general, the exercise consisted of making an exposition to represent a group of the developed project layouts and had to include the graphic content (Fig. 3). The documents and information had to be made available to the exposition visitor through 2D codes and AR techniques on mobile devices. Format and layout orders were established to include text, images, and graphs to represent the course exercises.

Students were required to incorporate the following elements into their final 3D presentations:

- QR code linking to the personal blog of the student where they have published advances and pre-deliveries in both 2D and 3D
- QR code linking to the 3D model so that it can be downloaded to the mobile device for augmented viewing
- Spontaneous markings generated by the student that overlap with the 3D model previously downloaded

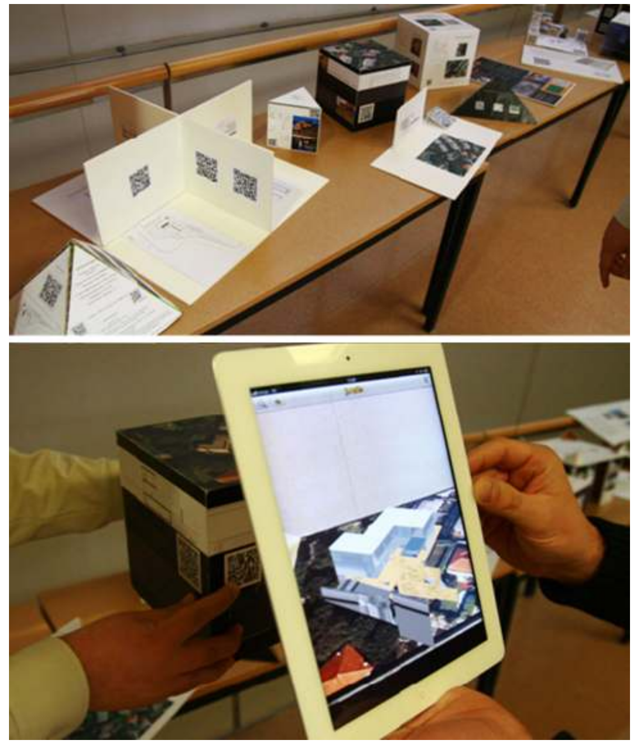


Fig. 3 Examples of final projects

- Rendered images of the project as well as information about it or the architect.

Conceptually, all of the requirements were designed based on the premise that students can use free options. If students were required to use the most compatible formats, the exercise would have been more complicated. Reaching this point, it should be noted that with the increasing number of applications, viewers, and systems that facilitate digital design, it is difficult to find one general solution among different professional sectors [54].

This working ambiguity is easily observed depending on the geographic area, with different preferred programs depending on the country and region and even according to the university or labor task within the same geographic area. In the Spanish architectural educational context, the products developed by Autodesk (San Rafael, CA, USA), a software leader related to CAD and BIM technologies that has free licenses for 3 years of the best known and most commonly used software in drawing and modeling in 2D and 3D, including AutoCAD©, 3DMax©, Maya©, and Revit©, are the foundations of architectural work today.

With regard to the visualization framework, the working systems and available programs for any format or device are innumerable. However, attention should be focused on the most common formats because of their frequent use and standardization.

With Autodesk products, 3D model generation is possible directly from programs in DWFx or OBJ format (one of the most widely accepted formats of AR applications), though this option is not available in all of their products. DWFx format, which is owned by Autodesk, allows for visualization and interaction on computer and mobile devices by installing Autodesk Design Review© or AutoCAD WS, which evolved to Autodesk360©. This format allows one to work on all types of models both locally and on the Internet, which is now known as "the cloud." The DWFx format is the functional equivalent to PDF3D [81] and provides a free solution, although it is not common to find presentations in Spanish teaching architecture framework that use this format [41].

However, if export is made using the OBJ format, accepted by applications typically used in the Spanish AR framework as Juanio® (Metaio Inc., Munich, Germany), Layar® (Amsterdam, Holland), and Augment® (Paris, France), which are compatible with IOS and Android and are free or low-cost solutions, a problem arises in the process of exporting the CAD/BIM models to the AR display system. It thus becomes necessary to import the CAD model with Google Sketchup© (Google, Inc., Mountain View, CA, USA), a visualization and presentation tool for all types of 3D models. This solution provides free student and professional licenses, allowing common CAD/BIM formats, such as DWG, DXF, OBJ, and 3DS, and raster image formats, such as JPG, GIF, and BMP, to be imported.

Because there was not enough time to provide students with a detailed explanation of how to perform the import, the teachers were required to implement this step. The students were thus required to submit their 3D models in CAD, and the teachers were responsible for generating an OBJ file with simple materials for students to mark it up during their presentation. If the student subsequently decided to improve the 3D model or change the OBJ model, it was his/her responsibility to generate the new model for the AR system visualization.

5 Results

As stated previously, to evaluate the degree of adaptation to and satisfaction with the proposed method, as well as the advantages of working with a mixed system of data collection, students were invited to voluntarily participate in the study.

Of the 79 students enrolled in the first course of "Informatics Tools I", 20 students had a final rating of NP (Not Present), i.e., they did not attended the classes or exams and were excluded from the study. Of the remaining 59 students, 48 took the two quantitative tests (81.35 % of the students who followed the course and 60.75 % of the students enrolled, taking into account NP students). For this evaluation, ISO 9241-11, which provides several usability guidelines to define effectiveness, efficiency, and satisfaction, was used. The tests were designed with two primary objectives: to obtain the technological profile of the student in terms of his/her use and habits surrounding mobile and Internet technologies and to obtain an overall assessment of the work.

To assess the academic level achieved after implementing the proposed project, the results of this course were compared to those from the previous academic year, in which a traditional methodology was used in the 2D and 3D design phases. To design the pretest or technological profile test, and the posttest or usage/satisfaction test, a structured test was used within the university's Intranet Moodle system. All of the questions were scored on a five-point Likert scale (1 = never or strongly disagree, 5 = always or strongly agree). The model used was based on previous projects [41].

For the qualitative study (using BLA), a balanced sample of 10 students (5 men and 5 women) who agreed to participate was randomly selected. In the following sections, the data collected are reviewed before discussing the results and their implications.

5.1 User profile and motivation: quantitative study 1

The first test, as shown in Fig. 2, was given once the first phase of the class ended, at a time when the students already knew the main characteristics of an architectural project. This phase had duration of about 2 months, which allowed for the students to gain a basic understanding of the subject at hand as well as of the basic concepts in Artistic Architectural Drawing, Technical Drawing, Construction, Architectural Mathematics, and Physics classes.

The objective of the test was threefold: to assess the technological profile of the student according to where and how he or she uses technology, to obtain a feedback on the theoretical/practical process in the 2D phase, and to characterize students' perception and knowledge of RA technology.

The results obtained should allow for a first approximation of whether the student is ready to use mobile technology and ubiquitous Internet connections for the publication of and interaction with architectural content. Additionally, student perceptions of the system used in the 2D process and the potentiality of RA will be compared with the second test to get a clear indication of the evolution of student perceptions of, motivation toward, and satisfaction with the proposed methods.

The first dataset (Fig. 4) shows almost unanimous use of laptops and smartphones. In-depth comparative analyses of

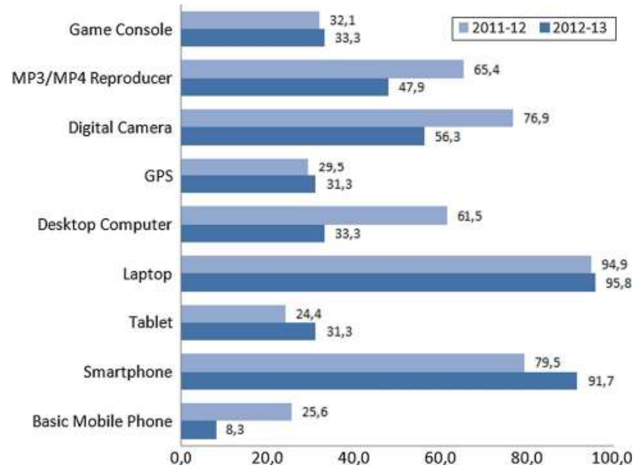


Fig. 4 Technology used in 2011–2012 versus 2012–2013

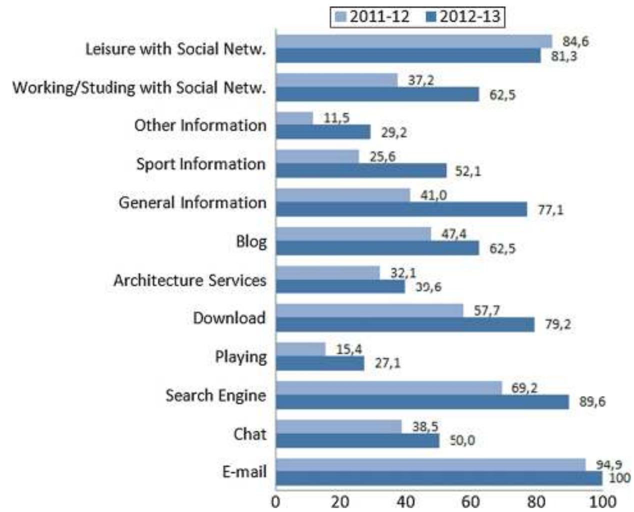


Fig. 5 Internet use

the responses to the same questions in the previous year (2011–2012 academic year, in the same subject and with the same profile of students, with a total of 78 students: 39 females and 39 males, mean age = 19.40 years, SD = 3.39) affirm that there is a growing commonality in the way that students communicate/work/study/interact with digital devices.

The comparative data show how the increased use of laptops and smartphones, which integrate technologies such as playing MP3s/MP4s and digital cameras, caused a sharp drop in the use of certain devices, especially desktop computers and basic mobile phones.

Conceptually, such high levels of mobile device usage, close to 100 % in the current course (Fig. 4), indicate that students are better prepared to work with systems and procedures online, which must be confirmed by additional questions in this round and at the end of the experiment.

Other data extracted from this first study show that about 84 % of students use computers for informational or social purposes, and this figure raises to 90 % for the study tasks. These figures are lower for mobile devices, although interesting trends can be observed: Currently, 64.6 % of students use mobile devices to search for information (an increase of almost 20 points over the previous year), about 77 % used for them for social purposes, while the proportion of students who use them for work and study is lower (an average of 30 %, still far below the 90 % usage of computers for these tasks).

The increased use of mobile devices and the decline of desktop devices are reflected directly by changes in connection locations: There has been an increase in the use of public Wi-Fi (from 17.9 to 39.6 % of students) and a decrease in connecting to the Internet on computers within the university (from 92.3 to 85.4 % of students) or at home (from 97.4 to 93.1 % of students).

In conclusion, addressing the first objective of this phase, it is found that the students in the sample observed are strong technology consumers, especially mobile technology, and frequently use all types of Internet services (as shown in Fig. 5), which favors the implementation new teaching methods that involve the use of technologies that are currently available to and accepted by students.

The next objective of this phase was to assess the degree of student satisfaction with the theoretical/practical methods used in the 2D representation. To address this objective, a set of three questions were constructed and evaluated on a Likert scale (ranging from 1: strongly disagree to 5: totally agree); the results are shown in Fig. 6.

The results show that 63.5 % of the students had a good degree of motivation to enact the proposed method (ratings of 4 or 5) and only 12.5 % of the students responded negatively (ratings of 2 or 1). Regarding the practical system used, 72.9 % of students gave "highly satisfactory" responses, and an even higher proportion (81.3 %) was satisfied with the usefulness of the content developed. While these data offered a highly positive valuation of the traditional method implemented in the 2D phase, it was not until the completion of the course that the results could be verified, by comparing students' perceptions of the two systems proposed.

Finally, in this first test, before specifically discussing the subject, questions were asked about three aspects related to the RA technology: the perceived degree of difficulty of use, the degree of usefulness in working with three-dimensional models, and the perceived usefulness of the technology to architectural studies.

As shown in Fig. 7, initially, students did not know how to assess the degree of difficulty in the use of such a technology, as was expected, and 97.9 % of the responses

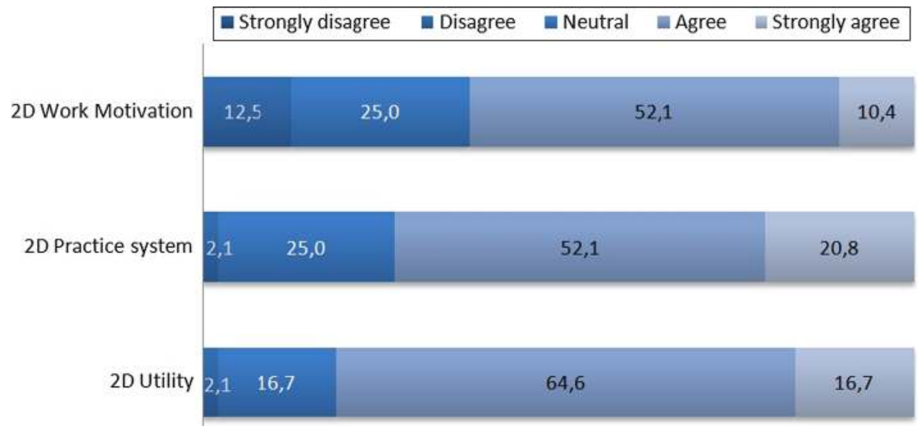


Fig. 6 2D method evaluation

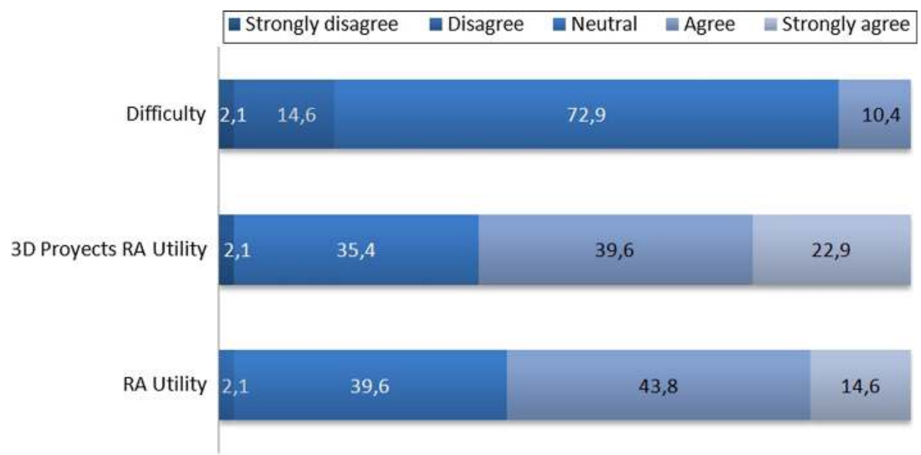


Fig. 7 Previous perceptions of AR technology

fell into the middle category (neutral or both slightly positive and negative). However, the students perceived the usefulness of AR technology in both 3D representations and in future architectural work, evaluating it with positive values ranging between 62.5 and 58.4 %, respectively, although there were still high rates of indecision (neutral responses: 35.4 and 39.6 %, respectively) while waiting for the practical experience of the second phase.

In conclusion, the study was carried out with a group of students that was uniform by gender, though not by origin. A total of 34 % of the group was foreign students, which could lead to a differentiation in basic education or prior knowledge. However, the results of the test profile reflect fairly homogeneous knowledge and technology use. Note that three persons in the group were hearing impaired; this profile level difference was not denoted with respect to the remainder of the class in terms of the technology use.

5.2 Usability test: quantitative study 2

The second test was realized after the second phase of the course, prior to the review and publication of the final marks, in accordance with the methodology shown in Fig. 2. At this point in the course, the end of the first half of the first academic year around the end of January, the students have already completed Construction I, Physics, and Mathematics, in addition to the basic concepts in Drawing and Descriptive Geometry.

The objective of this second test was threefold: to compare the efficiency of the two methods by comparing perceptions of the 2D system before and after having worked with methods for 3D viewing, to understand the perceptions students on the use of the technologies for 3D viewing (in particular, the AR), and to assess the degree of usability in general of the content, structure, and methodology of the technology. By focusing on the objectives mentioned above, the first analysis evaluated the traditional methodology (used in the 2D phase) based on student perspectives from the first test and from the same questions in the 3D phase.

Figure 8 shows a comparison of the pretest data (see Fig. 6) with responses to the same questions after the course was finished. The perceived utility of the 2D method was initially positive (agree or strongly agree) for 81.3 % of the sample, but only 32.4 % thought so at the second assessment. Neutral valuation increased from 16.7 to

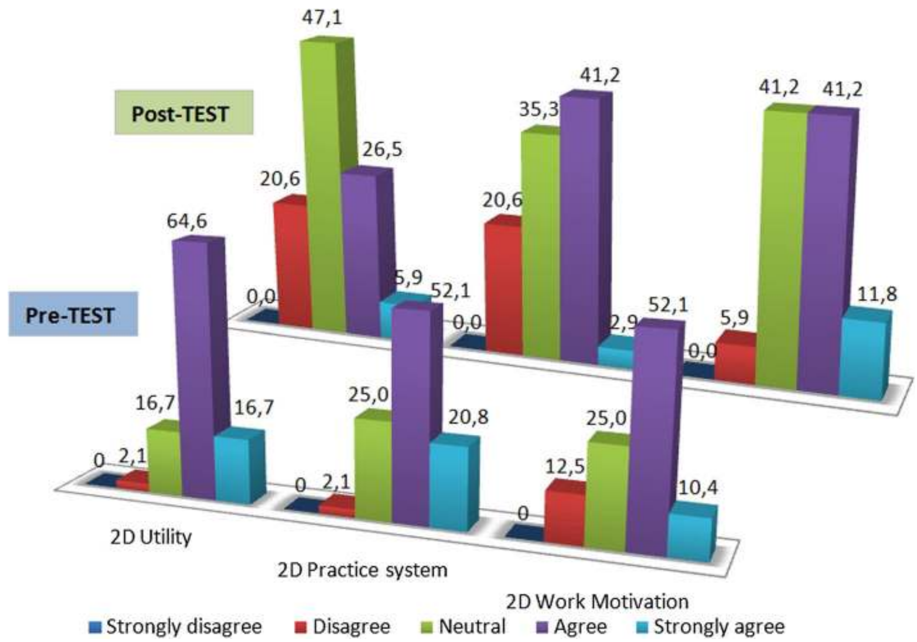


Fig. 8 Pre- and posttest results for the 2D method

47.1 %, and the slightly negative rating increased from 2.1 to 20.6 %.

As will be discussed later, the motivation behind this sudden change was explained in the private comments of students by the perception that it is easier to get the 2D architectural drawing from a 3D model than it is to do so in reverse, which expedites the procurement of quality printed layouts.

This trend was repeated in the responses to the next question, which examined the practical method used in 2D: Positive evaluations were reduced from 72.9 to 44.1 %, neutral evaluations increased from 25 to 35.3 %, and negative evaluations increased from 2.1 to 20.6 %. However, due to either the innate difficulty of working in 3D or the lack of working time reported by the students, responses to the question of motivation for using the 2D method did not vary greatly, perhaps due to the concentration of neutral responses (increasing from 25 to 41.2 %) and with the predominance of positive assessments (which only declined from 62.5 to 53 %).

Finally, when the students were asked about their motivation to practice the method, a decrease in negative values (from 12.5 to 5.9 %) was found, as well as greater concentration of neutral responses (from 25 to 41.2 %) with a slight decline in positive values.

The second objective of this phase focused on student perceptions of the use and usefulness of AR as a system for presenting architectural projects by comparing the system proposed with the method used in the 2D phase.

Figure 9 compares the results obtained before and after the exercise on how the students perceived the AR system.

To analyze the utility of AR, it is necessary to differentiate between the proposed experiment and overall perceptions. While in the first case, the values changed only minimally (positive ratings fell by 8.4 %, thus increasing negative ratings by 9.7 %), when usefulness was evaluated at a more global level, perceived usefulness drastically reduced by 33.1 %, a margin that is shared among the neutral responses, which increased by 17.5 %, and the negative responses, which increased by 15.5 %.

The possible reasons for these results and their relationship with the usual contents of architectural projects are described later in this paper. However, it can be affirmed that the reduction of utility observed has a direct relationship with the difficulty perceived by the students in the use of this technology, with an increase of 29.8 % (from 10.4 to 41.2 %) in students who felt that AR technology was difficult to implement or use.

Figure 10 shows the results of the comparison between the 2D and 3D methods used as well as the comparison between using the 3D visualization and a blog about AR techniques.

Based on the analysis of the latest data, the majority of students did not favor one method over another, giving a neutral rating to all questions. However, there was a slightly more positive perception of the 3D method versus the 2D method, both regarding ease of use (where 35.2 % of ratings were positive vs. 26.4 % that were negative) and perceived usefulness (29.4 vs. 14.7 %), as well as in general (26.5 vs. 20.6 %). In terms of the viewing methods used in the 3D phase, students mostly flocked to the DWFx format embedded in their personal blogs before working

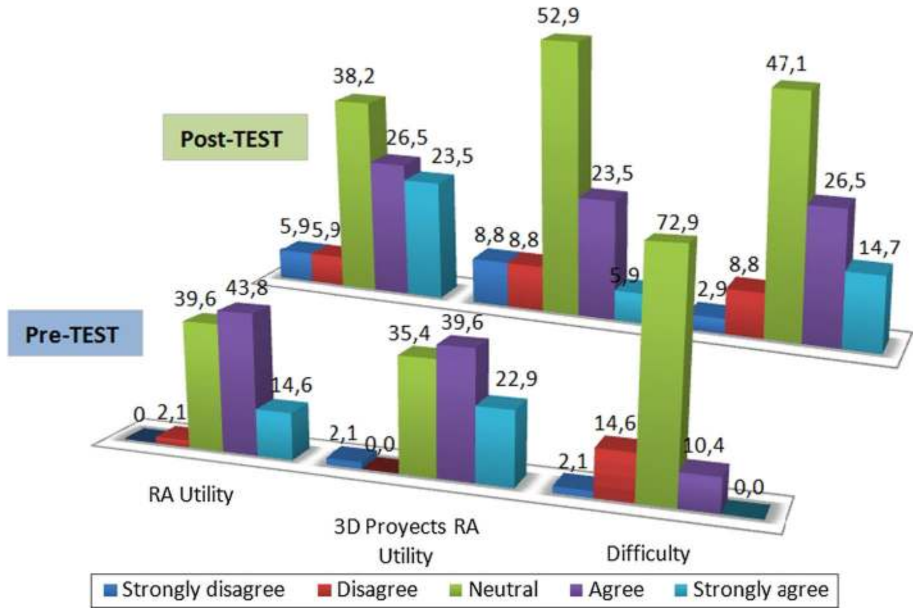


Fig. 9 Pre- and posttest results for AR perception

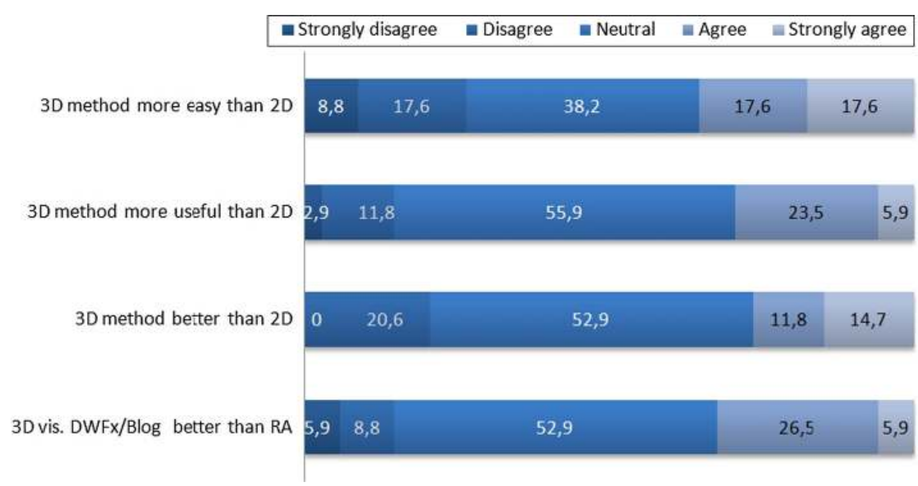


Fig. 10 Global 2D versus 3D visualization method comparison

with AR (32.4 vs. 14.7 %), probably because this method is much more direct and simple.

Figure 11 shows the perceptions of the students toward various specific elements of the experience, focusing on the degree of perceived usability. Again, the percentage of neutral answers is the largest, but the high positive assessment of almost all aspects, and in particular the documentation and structure of the exercise and the improvement provided by AR in the presentation of the architectural 3D models, can be emphasized. The only elements with low rates of positive responses, as already found in previous studies [62], are the definition of the final 3D models (23.5 %) and the stability of the display (20.6 %).

5.3 Final qualitative study: BLA implementation

Qualitative methods are commonly employed in usability studies and, inspired by experimental psychology and the hypothetical-deductive paradigm, employ samples of users who are relatively limited. Nevertheless, the Socratic paradigm from postmodern psychology is also applicable and useful in these usability studies because it targets details related to the UX with high reliability and uncovers subtle information about the product or technology studied [19].

This migration from the hypothetical-deductive paradigm to the Socratic paradigm was inspired by the paradigm shift in clinical psychology away from constructivism and toward other postmodern schools of psychotherapy.

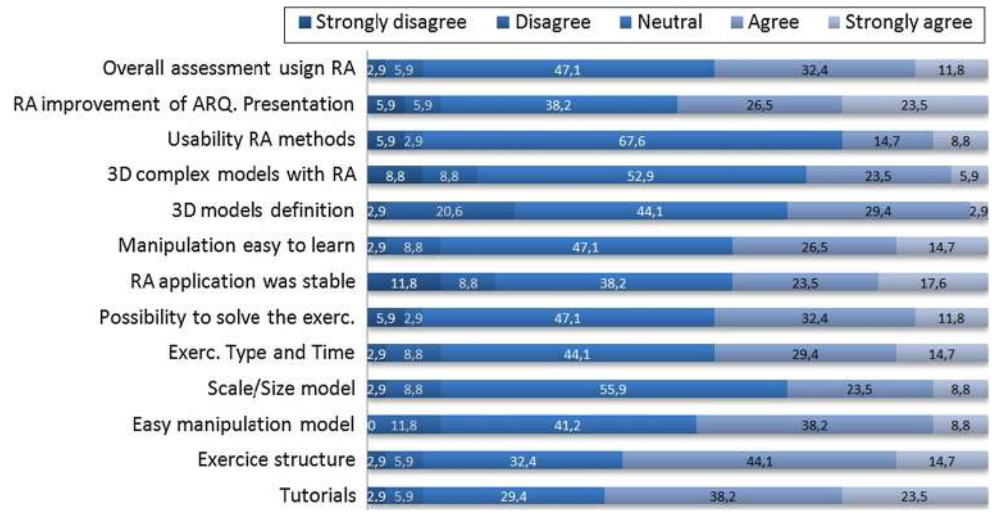


Fig. 11 Usability evaluation and student satisfaction with different aspects of the experience

This psychological model defends the subjective treatment of the user, unlike the objective hypothetical-deductive model [83].

Starting from the Socratic paradigm basis, the BLA system (Bipolar Laddering) has been designed. BLA method could be defined as a psychological exploration technique, which points out the key factors of user experience. The main goal of this system was to ascertain which concrete characteristic of the product entails users' frustration, confidence, or gratitude (between many others).

The BLA method works on positive and negative poles to define the strengths and weaknesses of the product. Once the element is obtained, the laddering technique is going to be applied to define the relevant details of the product. The object of a laddering interview was to uncover how product attributes, usage consequences, and personal values are linked in a person's mind. The characteristics obtained through laddering application will define what specific factors make consider an element as strength or as a weakness. BLA performing consists in three steps:

1. Elicitation of the elements: The implementation of the test starts from a blank template for the positive elements (strengths) and another exactly the same for the negative elements (weaknesses). The interviewer (in this case an academic tutor) will ask the users (the student) to mention what aspects of the subject and experiment they like best or help them in their tasks. The elements mentioned need to be summarized in one word or short sentence. This first step may be open or limited, i.e., positing a number of aspects without limits or reducing them to a specific number, as in the present case where every student was asked to indicate three positive aspects and three negative ones;
2. Marking of elements: Once the list of positive and negative elements is completed, the interviewer will ask the user to mark each one from 0 (lowest possible level of satisfaction) to 10 (maximum level of satisfaction);
3. Elements definition: Once the elements have been assessed, the qualitative phase starts. The interviewer reads out the elements of both lists to the user and asks for a justification of each one of the elements performing laddering technique. Why is it a positive element? Why this mark? The answer must be a specific explanation of the exact characteristics that make the mentioned element a strength or weakness of the product.

Once the element has been defined, the interviewer asks to the user for a solution of the problem he just describes in the case of negative elements or an improvement in the case of positive elements. Figure 12 shows an example of the BLA test used:

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

1. Positive (Px)/Negative (Nx): The student must 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 functional aesthetic (see Table 1), in front of the negative aspects that did not facilitate work or simply need to be modified to be satisfactory or useful (see Table 2);
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 only given by one of the students (particular elements) were separated according to the coding scheme shown in Tables 1 and 2.

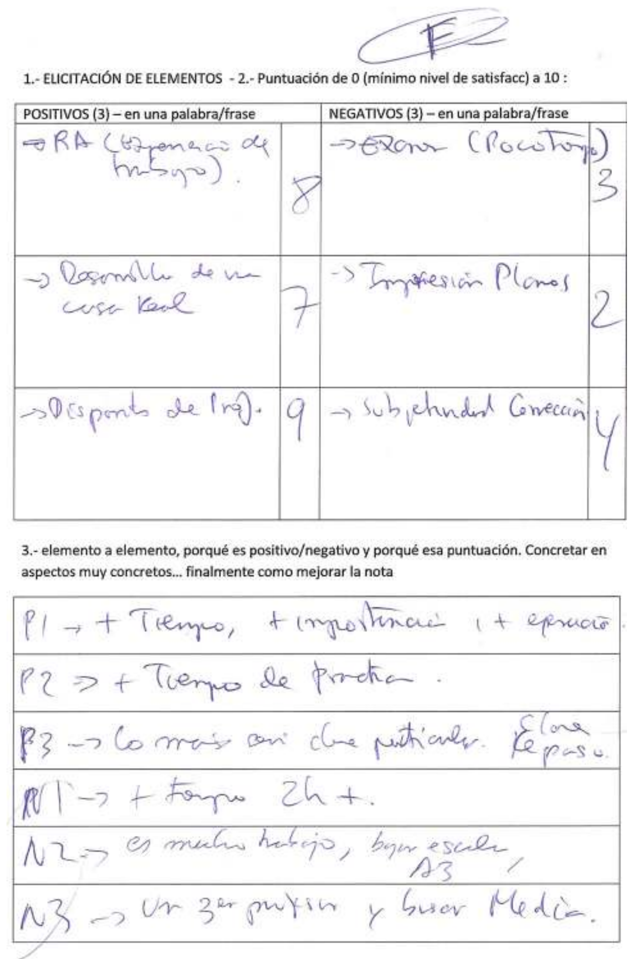


Fig. 12 BLA sample test

The common elements that were mentioned at a higher rate are the most important aspects to use, improve, or modify (according to their positive or negative sign). The particular elements, due to their citation by only a single user, may be ruled out or treated in later stages of development.

The individual values obtained for both indicators, positive and negative, are shown in the following Tables 3 and 4. Once the features mentioned by the students were identified and given values, the third step defined by the BLA initiated the qualitative stage in which the students described and provided solutions or improvements to each of their contributions in the format of an open interview.

Table 5 shows the main improvements or changes that the students proposed for both positive and negative elements. Only the "common" aspects, which were mentioned by at least 2 of the students, have been included.

At this point, before discussing the results, it is interesting to identify the most relevant items obtained from the BLA, by high rates of citation, high scores, or a

Table 1 Positive common (PC) and particular (PP) elements

	Description	Av. Score (Av)	Mention Index (MI) (%)
1PC	Organization of the subject	8.33	60
2PC	AR method vis. versus 2D method	8.25	40
3PC	Utility of acquired knowledge	9.75	40
4PC	Faculty (quality/availability)	9.25	40
5PC	Improved presentation of projects	8.50	20
6PC	Improved 3D spatial skills	7.00	20
7PC	Detailed work in 2D method	8.00	20
1PP	Easy contents and technology	8.00	10
2PP	Digital deliverables	7.00	10
3PP	Working with real projects	7.00	10
4PP	Level of requirement	9.00	10
5PP	Blogging tasks	8.00	10
6PP	Practice and exam levels	9.00	10

Table 2 Negative common (NC) and particular (NP) elements

	Description	Average score	Mention Index (%)
1NC	Excessive content versus time	3.86	70
2NC	Application crash	3.60	50
3NC	Blogging task	4.25	40
4NC	Exam time	3.75	40
5NC	More AR tutorials	3.50	40
6NC	Working with printed layouts	3.00	30
1NP	Subjective evaluations	4.00	10
2NP	Begin with 3D in phase 1	5.00	10
3NP	Working with groups	0.00	10

combination of both. Because work is carried out following an open-ended method, some of the above elements were not at the focus of the study (i.e., the evaluation of new visual techniques in the teaching field). Thus, only the elements closest to the motive of the study are highlighted.

Concerning positive remarks, the organization of the subject (MI: 60 %, Av: 8.33), the usefulness of the knowledge acquired (MI: 40 %, Av: 9.75), and the novelty and appeal of the AR methods over the traditional 2D methods (MI: 40 %, Av: 8.25) can be highlighted. In short, the enhancements to the methods for presenting architectural projects should not be modified in the redesign process.

In terms of the main negative comments, students clearly identified a lack of time or an excess of content for practical realization especially in 3D (MI: 70 %, Av: 3.86), problems with the applications used and their stability (MI: 50 %, Av: 3.60), as well as greater detail or more information per use, and the working procedures for the use of

Table 3 Individual scores for PC and PP elements

Element Code	Male					Female				
	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9	User 10
1PC	7	7	10	8	–	–	8	–	10	–
2PC	9	–	–	7	–	8	–	–	9	–
3PC	–	–	10	–	9	–	–	10	–	10
4PC	–	–	10	–	–	9	8	10	–	–
5PC	–	–	–	–	9	–	–	–	–	8
6PC	–	8	–	–	–	–	–	–	–	6
7PC	–	–	–	8	–	–	–	–	8	–
1PP	–	–	–	–	8	–	–	–	–	–
2PP	–	7	–	–	–	–	–	–	–	–
3PP	–	–	–	–	–	7	–	–	–	–
4PP	–	–	–	–	–	–	9	–	–	–
5PP	–	–	–	–	–	–	–	8	–	–
6PP	9	–	–	–	–	–	–	–	–	–

Table 4 Individual scores for NC and NP elements

Element code	Male					Female				
	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9	User 10
1NC	2	–	3	–	5	–	4	4	6	3
2NC	–	3	4	–	4	–	2	–	5	–
3NC	4	–	–	4	–	–	–	–	4	5
4NC	–	4	–	4	–	3	–	–	–	4
5NC	–	–	4	3	4	–	–	3	–	–
6NC	3	4	–	–	–	2	–	–	–	–
1NP	–	–	–	–	–	4	–	–	–	–
2NP	–	–	–	–	–	–	5	–	–	–
3NP	–	–	–	–	–	–	–	0	–	–

Table 5 Proposed common improvements (CI) for both positive and negative elements and for common and particular items

	Description	Mention index (%)
1CI	More practice time	80
2CI	More exam time	50
3CI	More AR explanation	50
4CI	More rendering and 3D explanation time	50
5CI	Better spacing of 2D deliveries	40
6CI	Promoting work with AR technologies	30
7CI	Begin in phase 1 with 3D explanations	30
8CI	More personal duties	30
9CI	More explanation of the blog	30
10CI	More 2D explanation	30
11CI	More explanation of AutoCAD tricks	30
12CI	Explanation of more CAD and AR tools	20
13CI	More refresher classes	20
14CI	Equal difficulty of practices and exams	20
15CI	Improve the equipment of the classroom	20

AR systems (MI: 40 %, Av: 3.5), aspects that could be related to improving the process by increasing the stability of the applications. Technically, these would be the main aspects to modify in future iterations of the proposed method. Table 5 shows the features with the highest rates of mention in proposals for improvements (between 40 and 80 % of the students mentioned them).

In summary, two key issues have been identified: the lack of time in implementing the practices and the need for supporting documentation that would allow giving more information to the students about the processes involved with AR, and the way to solve problems in the implementation of the exercises. This last aspect may encompass the need to increase the amount of time for explanation and practice of the exercises related to the use of the blog and the AR. Thus, a determining factor in the perception of the student of the proposed methodology was the lack of time. It was recurrently found that there was insufficient time for completion of all the proposals submitted, although the students positively valued, and were not in favor of reducing or eliminating these exercises, as they appreciated their usefulness in the medium and long term.

6 Discussion

From a quantitative point of view, a diachronic or longitudinal research has been conducted, which usually lends itself to studying the relationship between independent variables (structure of the course, implemented technologies, methods, etc.) and a dependent variable, which in the present case would be academic performance. The sample that was used defines this research as "quasi-experimental", given that it was not possible to randomly establish working groups, and the groups were selected according to the academic year in which they studied. A great limitation of this model is the difficulty of assessing whether the changes observed were due to the intervention itself or to other factors not controlled for. In cases in which work is carried out with fixed groups, statistical theories strongly discourage using analysis of covariance (typical when one can have groups of control systems and random sampling). The solution is to work with the correlation of results, because of identical variables in the pre- and posttests, making it possible to analyze the change in scores [84]. The appropriate statistical analysis will depend on the grouping of the subjects (equalized or by blocks) and the samples to compare: Usually, "Student's *t* test" or the "factorial analysis of variance" is applied to related samples. These analyses always require additional ones, and the relationship of the quantitative data with the data obtained from the qualitative study conducted using the BLA method will be assessed, providing an innovative character to the experiment.

Having defined the starting point for the analysis of the data obtained, and turning back to the initial test or profile test, one can affirm that students who currently take architecture classes in the authors' faculty mostly use mobile devices of latest generation, also called smartphones, for all kinds of activities (see Figs. 4, 5). The results show a growing use of devices such as smartphones and tablets as opposed to desktop computers (which were more common in the last 5 years). This high implantation rate positively predisposes students to using these devices in an educational way, increasing their motivation to understand course content, thereby improving their academic performance. This hypothesis is confirmed when students' academic results in the authors' class from the past 5 years are analyzed.

As shown in Fig. 13, the implementation of the EHEA, which in the case of the class studied mean the temporary reduction of a year-long class to a semester-long class and the loss of 50 % of classroom hours, marks a clear decline in the final grades for both 2D and 3D projects. Analyzing the structure and contents of previous courses, the possible causes for this decline are multifold: the lack of foresight and adaptation of the amount of content and its difficulty according to the new temporary plan, especially during the first year of implementing the EHEA. In the 2010–2011 academic year, the students needed a greater number of hours dedicated to some topics designed for annual testing (in previous years) and could not learn them in a much more short and intensive way. Giving students less time to assimilate theoretical concepts led to a sharp decrease in the quality of the student projects. This course provided instruction on both 2D and 3D systems and followed the same structure as past courses, which included a constant review process of the projects that the final grade was based on, and scores in the phase 3D were always higher than those in the 2D phase.

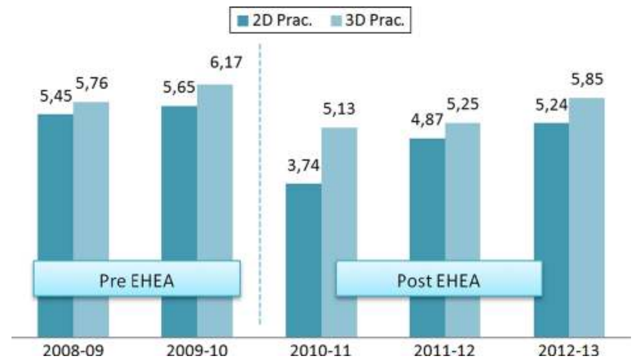


Fig. 13 Academic results (practice phases), 2008–2010: prior to implementation of the EHEA; 2010–2013: after implementation of the EHEA

In the second year of the EHEA (2011–2012), the faculty made changes to adapt the subject to the new situation and, in particular, adapted the type of practices (reducing the complexity of the model) and explored new methods for working (reducing the printed deliverables and searching for digital outputs to minimize the time commitment [60]). The new proposal succeeded in boosting academic outcomes, especially for the 2D project, without having an entire year to do so. For comparison, we have using the analysis of variance (ANOVA) using a threshold of 0.05, getting significant differences between the qualifications of the courses 2011–2012 and 2008–2009: $F = 9.05$, $p = 0.002$.

With the proposed method implemented in the academic year 2012–2013, it was concluded that there is no statistically significant differences ($F = 3.276$, $p = 0.075$), between 2008–2009 (with a mean of 5.45, one can consider this year as a previous indicator, because of in pre-EHEA period, all 2D practice results are between 5.25–5.78) and 2012–2013 ($M = 5.24$), as the statistical significance (two-tailed) is 0.075, which exceeds the threshold of 0.05.

These results indicate that the adaptation of the content and processes designed for the 2D phase led to results comparable to the average academic results that were historically found in this subject. However, this positive outcome should be questioned, because student performance did not increase (general purpose of the EHEA), and student perceptions of and motivation for the 2D work suffered ostensibly once this method was compared to the 3D method (as mentioned previously in evaluating the results of Fig. 8).

Although this interpretation is extracted from little quantitative data that are very generic, the mixed approach used allows to corroborate the quantitative data with the qualitative data collected using the BLA (shown in Tables 1, 2, 5). Although the structure of the course was highly valued, the excess content regarding the time and the appeal of the 3D method with respect to the traditional 2D method make it necessary to modify this first phase, as the students desired increased explanation and development time and some aspects of the course were incompatible with the credit system proposed by the EHEA and implemented by the university.

If the results of the 3D projects are analyzed, which were added to the technological innovation described in this paper, and are compared with those of the previous courses, one notices a significant improvement during the post-EHEA period ($F = 3.48$, $p = 0.05$) and results equal to those of the pre-EHEA period, during which there were no significant differences between courses ($F = 0.30$, $p = 0.57$).

This improved academic performance can be attributed in part to the course curriculum, the methodology of visualization with AR, and the utility and enhancement that it provided in working in 3D, all of which resulted in positive data obtained from the BLA. However, there are a number of negative aspects (Table 2) and solutions proposed (Table 5) by students that have a direct impact on the 3D phase, including the lack of time for practical realization and for explaining RA and the techniques for rendering in 3D, as well as a lack of stability of the applications and models in RA. Comparing the academic results with all of the negative aspects and improvements that were cited in the BLA and those that can be drawn from the quantitative data (Figs. 9, 10, 11), it is clear that the students appreciated and were highly motivated to work in 3D, as this is a very useful architectural method; nevertheless, they observed that it is a difficult domain that is further complicated when working with advanced models, which requires greater time for projects and explanations.

In evaluating RA as a working tool, RA was deeply appreciated both in the quantitative stage (Figs. 9, 10) and in the qualitative stage (Table 1), although the students questioned the usefulness and stability of the system when their projects or models were more complicated. In such cases, working with online systems such as that provided by the DWFx is valuable because they render the learning process fast and stable and allow for more user-friendly interaction (Fig. 10). The BLA method has shown that it is necessary to increase the time for the RA explanation and project, as the perception of the students is that this extra time would help them to improve the stability as well as the final quality of the work.

7 Conclusions

The mixed method used has demonstrated its usefulness as a dynamic system for capturing information related to students' experiences with technological elements in education.

Although mixed methods are common in UX and HCI, in technological teaching and, more specifically, in the architecture teaching framework, quantitative methods are commonly used. Using a mixed system expands the innate limitation of qualitative methods, which involve the users' emotional subjective responses. Qualitative methods are not just a problem, but a step forward; in addition to identifying new work variables, qualitative methods enable to obtain additional information from the quantitative variables that would otherwise have not been achievable. The main drawback of the mixed method described is the need to design quantitative surveys with questions adapted to the possible answers to the qualitative methods. Otherwise, it is possible to obtain differentiated data between the two types of studies and analyses, and would thus be impossible or very difficult to relate them later.

The main advantages demonstrated focused on the identification of aspects related to the design process, and the data were much more specific than those that would have been obtained through quantitative methods only, which is usually the focus of experiments on general questions. In the case presented, data were obtained that demonstrate how the implementation of the EHEA collided heads-on with learning methods that were based on the practical experiences of the users. By including in the total number of credits for the course the hours that students dedicated to personal work, the hours available for academic work declined (with respect to what was previously the case), confirming the need to add back the required time for learning, practicing, and assimilating the concepts that subjects taught for only a semester lack. Reduced time leads to teaching overload or the simplification of the material, which both negatively affect student motivation.

Focusing on the main objective of the study, student motivation and satisfaction with the proposed system were evaluated, obtaining qualitative feedback for the main items that, according to the students, should be implemented in using RA as a common tool for visualization of and interaction with 3D models in architecture education. It has been demonstrated how the proposal method not only improves academic performance but also generates a high degree of motivation and satisfaction among students, which leads to a greater involvement in the subject matter and its contents, as described in the Sect. 6.

The initial hypothesis set in the Sect. 1 was premised on the concept that with a minor investment of time and the use of visual mobile devices, students could obtain better results through having more motivating and satisfying experiences; this hypothesis has been confirmed in part. Although it has been demonstrated that the use of mobile technologies and visual systems of the latest generation is more motivating for students, they do not reduce the investment of time because they required more hours of explanation, practice, and debugging to create the final projects. However, neither the lack of time nor the need to invest more to achieve the objectives of the course is a variable that adversely affects the experience; they actually confirm the motivational nature of the experience and are aspects to target for improvement in future iterations.

For future directions of work, two possibilities have been clearly identified: the adaptation of content to people with disabilities and a study of the emotional user response to content displayed according to their profile and the technology used. While the rules of accessibility and usability are clear and commonly implemented in Web browsing, in mobile technology, different interfaces and developers with isolated applications that need manual configuration to adapt to the users' profile are found. This aspect, perhaps unrelated to the basic content of an architecture degree, is being made available to the Faculty within Multimedia Studies, such as under the research line defined as "tele-assistance".

For example, and as a suggestion from one of the deaf students who conducted the experiment, it would be interesting to label information or include textual information in the virtual elements to provide more information on the model. In a similar way for blind people, the example could include audio items that are activated when the device recognizes the proximity (through GPS) to the QR mark; the device could then narrate the relevant information from the model. Currently, and in collaboration with the Graphic Expression Department of the Architecture Faculty of the Polytechnic University of Catalonia, projects are underway for an urban display focusing on the inclusion of textual elements and audio for people with disabilities.

The second line of development would be to study the emotional behavior of users according to their typology and the content. In this regard, previous experiments conducted by the authors' team could be the foundation of this work [85–87].These experiences are based on known emotional assessment models used in such wide-ranging areas, such as psychology, neuropsychology, and sociology [88, 89].

Acknowledgments This project was made possible by the Fundamental Research Project Not Oriented of the VI National Plan for Scientific Research, Development and Technological Innovation 2008–2011, Government of Spain, N_EDU-2012-37247/EDUC, titled: "E-learning 3.0 in the teaching of architecture. Case studies of educational research for the foreseeable future".

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