Academic performance assessment using Augmented Reality in engineering degree course

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***Abstract*— The main goal of this report is to address the implementation of Augmented Reality (AR) technology in a university teaching context using different mobile devices. The specific contents and evaluation methodologies have been developed in the field of building engineering degree, where this technology offers potential advantages in the spatial training processes. The objective is to evaluate the system usability and measure academic performance improvement by using Hand-Held AR (HHAR) in educational environments related with the field of architecture, civil and building engineering. This method is validated through a case study where building engineering students were able to visualize a virtual complex models process overlapped onto a real environment. The results obtained from the students' PRE and POST tests as well as questionnaire responses show high qualification levels in effectiveness, efficiency and satisfaction. In addition, a significant improvement was found in the overall performance of the students of the experimental group.**

Keywords—augmented reality; educational research; mobile learning; Human-Computer interaction; usability assessment

I. INTRODUCTION

In addition to the superimposition of virtual objects on real environments, the features of AR are usable in a wide range of applications in the engineering and construction fields. These features offer potential advantages in all stages of a construction process [1], from conceptual design to building systems management and maintenance throughout its service-time. Virtual models, once overlapped to real space, can provide additional information for a better understanding of the building, thus contributing to a greater efficiency in construction processes, rehabilitation or building maintenance.

In this study, we focused on the implementation of new digital technologies for learning building construction and maintenance within the Technical Projects II course in the School of Building Construction (EPSEB) (UPC-Barcelona-Tech). In general, a synergy between the traditional methodologies and new AR technology was proposed to visually create hybrid (virtual and real) construction processes. In this study, we tested the process of opening a void in a load-bearing wall. Students blend the physical and virtual worlds; thus, real objects (markers) are used to interact with 3D digital content and increase shared understanding. We used textured light maps to incorporate lighting conditions from surroundings and introduced "occluders" for a better integration of the setting in its actual location [2]. The objective was twofold as follows: to evaluate the feasibility of using AR technology on mobile devices in educational environments and to assess the students' academic performance improvement. To accomplish this task, we compared the following two scenarios: S1 (based on slides and traditional methodologies) and S2 (based on augmented reality technology on mobile devices). The research questions were as follows:

1. What is the student's degree of satisfaction and motivation using this new methodology?

2. Are there any differences in academic results depending on which of the two teaching scenarios proposed are used?

3. Is there any relationship between the system usability and the student's academic performance?

In the first case, various studies have been conducted to evaluate Virtual Environment (VE) usability [3, 4]. Our case was based on ISO 9241-11, which provides usability guidelines as follows: effectiveness, defined as the user's ability to complete tasks during the course, in relation to "accuracy and integrity"; efficiency of the assigned resources related to the expenditure of time and effort for solving the proposed exercise; and satisfaction, understood as the subjective reactions of users regarding the course. In the second case, to evaluate academic performance improvement, we compared the final results between the control and experimental groups. Finally, compound indicators were constructed from the students' responses to correlate the three usability components with their academic performance. The results obtained by the students' POST training test and questionnaires responses demonstrated that by combining an attractive technology and AR-involved user-machine interaction, the students feel more motivated, and their graphic competences and spatial skills are increased in shorter learning periods. In addition, their academic performance is greatly improved. However, no significant correlation was found between the usability and academic performance.

II. THEORETICAL, PEDAGOGICAL AND DIDACTIC FOUNDATIONS

Learning, by definition, is the process by which memories are built, and memory is the result of learning [5]. In recent years, the desire to improve the learning process has led to the

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transition to technologically enhanced classrooms, where computers, media players, interactive whiteboards, Internet, Web 2.0 tools, and games have been incorporated. E-mail and mobile phones have transformed the way we communicate, and the list of technologies that can be useful in the learning processes is large and constantly growing, making it difficult to define which may or may not be suitable for learning [6]. On the other hand, we cannot affirm that using technology will lead to an increase in the motivation, satisfaction, or academic achievement of students. We need to evaluate and control how the technology must be incorporated into teaching because there are some risks that we need to control before we can improve not only the curriculum but also student skills and knowledge. 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.

More recently, immersive technologies in virtual and AR worlds have been used in some specific educational frameworks, specially related with 3D data visualization. The usefulness of these technologies has been assessed by numerous international projects [7-14]. These studies, which used AR in the area of entertainment and education, demonstrated the great potential of this technology. However, in education, it may still be considered as a new tool, requiring further investigation that gives special attention to user experience and learning processes [15]. Despite the ongoing effort to implement technology, there is also the need to immerse students in new learning environments, which are continuously changing [16]. In the meantime, teachers face the challenge of constantly being up-to-date in providing new forms of teaching and focusing on the acquisition of generic skills, in which students must construct their own knowledge through constructivism, as proposed by Piaget [17], and meaningful learning, as proposed by Ausubel [18]. In contrast, we frequently find situations in the classroom where educational contents are simply exposed and presented without any interaction with the student. When new concepts are received passively and content is just memorized, students may get bored easily and, consequently, minimize their learning. Student motivation is essential to reverse this situation [14].

AR can help improve the learning process performance by rectifying this situation [14], [19]. AR and virtual reality (VR) share some common features, such as immersion, navigation and interaction [20]. However, AR has two main advantages as follows: to allow collaborative experiences in a real setting, which lets users work with computer-generated objects as if they were real objects in a real environment in real time, and tangible interaction which works by superimposing virtual objects in a real environment through markers allowing users to modify and manipulate the scale, position, and location of virtual objects. Therefore, it can be concluded that AR by providing new interaction possibilities, promotes active student participation in its own knowledge construction and, becomes a suitable medium to be used in schools [21]. In our field of study, construction processes, the AR technology features would allow a "completed" reality superimposed onto the real environment. This technology could create a virtual image of something that does not exist as a result of the analysis of existing building systems (structural, facilities, envelope, etc.). Additionally, this technology could facilitate rehabilitation and maintenance tasks as well as systems verification, update and interactivity in the same place, and, in real time, could promote more efficient management and control processes of building constructive elements.

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 [22], and specifically AR, for the visualization of architectural design helps to adapt designs to the environment, avoiding problems of scaling, lighting and texturing [23-26]. 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 [27]. During the case study described below, we implemented the AR technology and applied these principles to future construction engineers with the purpose of increasing their learning and obtaining greater efficiency while performing these tasks, which are traditionally handcrafted and slightly technical, with a preliminary design of the experiment in [28].

III. Case Study

The Technical Projects II course is primarily intended to provide students with the technical capacity to tackle construction and execution issues of a technical project. In summary, students should be able to technically analyze project documents and apply them to the execution of studies at the end of the course. The subject is divided in the following three blocks: structural false-work, building facilities, and building envelope. As mentioned previously, we worked on the first block, focusing on the process of opening a void in a load-bearing wall. At the end of this practice, the student should be able to do the following: identify different methods to implement this construction process, analyze the structure of a building, and quantify structural loads to replace a structural element, and calculate and design all the elements in a practical case.

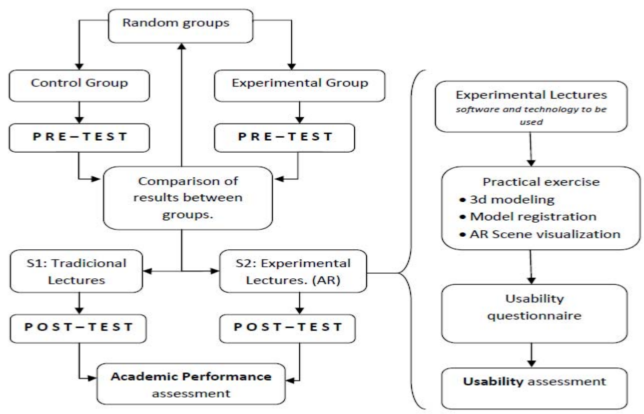

Fig. 1. General scheme of the methodological process

A. Procedure

To evaluate the usability of AR technology on mobile devices and assess the students' academic performance improvement, the experiment was performed in the following three stages: PRE-Test, lectures, and POST-Test (Fig. 1). The total number of students enrolled in the course was 183. At the end of this first block, after the students' evaluation, we excluded those students who had not performed any of the tasks required for assessment (PRE-Test, practical exercises, or Final test), so the final number of students who participated in the experiment was 146.

These remaining students were divided into 4 groups as follows: 3 control groups (1M, 2M, and 3T) and 1 experimental group (4T). The control groups followed the traditional course based on slides (Scenario 1), and the experimental group was involved in AR-specific training (Scenario 2). This group used a self-developed application (named U-AR) under the Android platform.

On the first day of the course, all students completed a test (PRE) that was used to determine prior knowledge on the subject. This test is based on assessments used in previous years. It was useful to verify that all student groups were similar before beginning the study.

Conducted in three sessions, all students participated in a conventional class that was based on lectures and practical exercises. The participants, divided into small working groups of 5 or 6 students, consulted and clarified any uncertainties with the teacher. The students from the 4T group (experimental), however, received an additional lecture that taught the application operation and how to manage distributed contents to be visualized through the AR. In addition, these students received detailed instructions of the analysis to be performed through their devices.

Finally, the construction process to be visualized was explained, and 3D virtual models were distributed. "Fig. 2" shows the process where the students select a place in the school and, through their mobile devices, watch "in situ" the five steps in the following construction process: reinforcement of existing foundations, false-work for shoring and temporary support loads, demolition of the brick wall, placement of columns and beam to support final loads, and false-work removal and final state (Fig. 2 and 3).

Once the students' training in this block was finished, all students (from control and experimental groups) were evaluated using the following criteria (POST-Test):

- (10%): Practical exercises at the beginning of each session

- (30%): Theoretical Test

- (60%): Final presentation, with constructive descriptions and images of the entire construction process

Finally, the students in the experimental group were also required to answer a usability questionnaire to obtain their opinion regarding the course and technology used.

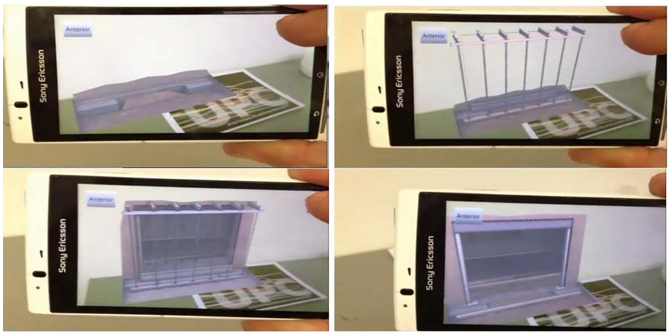

Fig. 2. Images of the construction process to open a void in a load-bearing wall using AR on mobile devices

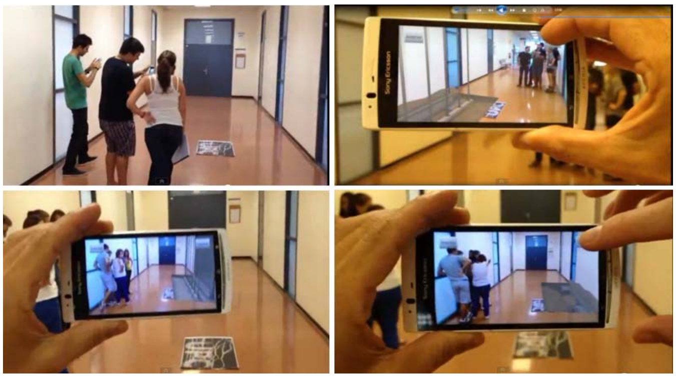

Fig. 3. Images of experimental group students viewing a construction process using their mobile devices

B. Usability assessment

As mentioned before, we evaluated system usability using questionnaires based on ISO 9241-11. The average of the responses, related to effectiveness, efficiency and satisfaction, were very similar and ranged from 3.31 to 3.46 out of 5 (Fig. 4). The overall assessment was rated at 3.51 points out of 5. Similar results were also found in previous studies [29], which confirm the feasibility of using this technology in educational environments.

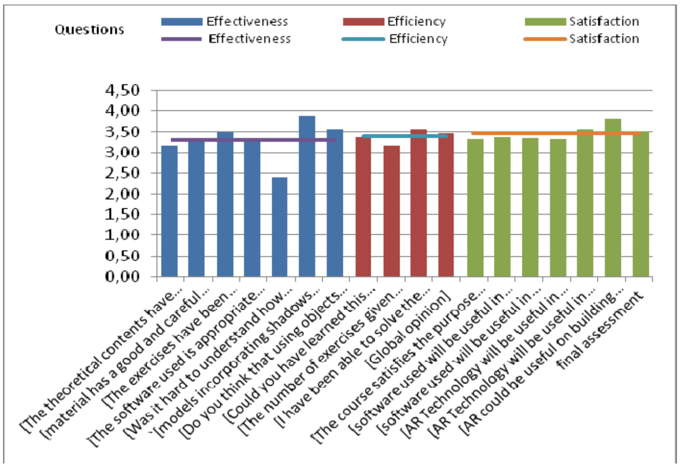

Fig. 4. Student responses to usability questionnaire

However, independently, the response interpretation is complex. To provide a clearer interpretation and allow the information to be presented in a brief, concise manner, there is a need to group these responses. Because of, it is necessary to construct composite indicators, which in our case are: knowledge level/previous training, effectiveness, efficiency, satisfaction, and usability indicator. These indicators do not provide a full explanation of the latent variable but allow obtaining "quality" indicators for each student. To achieve this interpretation, we used Principal Component Analysis (PCA). Once major components and contribution rates were estimated, we assessed each of the students according to an index derived from a general expression that weighs the scores for each principal component to the square root of the variance as follows [30]:

$$I_{mj} = \frac{\sum_{i=1}^{r} Z_{rj} \cdot \sqrt{\lambda_r}}{\sum_{i=1}^{r} \sqrt{\lambda_r}} \qquad (1)$$

In the equation (1), I_{mj} represents the composite indicator to be achieved (efficiency, satisfaction, effectiveness, etc.) for each j-th student; Z_{rj} score is the r-th component (factor) for the j-th student; and $\sqrt{\lambda_r}$ is the square root of the "eigenvalue" for that component, ensuring that the components with higher explained variance have a greater weight in the index construction.

TABLE I. RESULTS OF FIVE STUDENTS CORRELATING QUESTIONNAIRE RESPONSES WITH USABILITY RATINGS

Main Variables	Student 122	Student 125	Student 48	Student 67	Student 41
W_contents	5	2	2	5	3
W_material	4	2	2	5	4
W_exercises	5	1	2	5	5
W_software	5	2	3	5	5
W_course_purpose	5	2	3	5	5
W_learn_indep	3	3	3	4	5
W_num_exercises	4	2	3	4	5
W_solve	5	3	3	4	5
W_Global_opinion	5	2	1	5	5
T_hard_program	1	2	1	3	1
T_soft_useful_student	5	2	2	5	5
T_soft_useful_engineer	5	3	3	5	5
T_AR_useful_student	5	2	1	5	3
T_AR_useful_engineer	5	3	2	5	3
T_AR_useful_areas	5	2	2	5	4
T_shadows	5	2	2	3	5
T_occluders	5	2	2	3	4
Final_assessment	5	2	2	5	4
Responses average	**4.56**	**2.17**	**2.17**	**4.50**	**4.22**
EFFICIENCY	0.73	0.03	0.06	0.57	0.89
EFFECTIVENESS	0.96	0.00	0.21	0.66	0.87
SATISFACTION	1.00	0.15	0.13	1.00	0.74
USABILITY	1.00	0.00	0.09	0.82	0.93

These constructed indicators cannot be measured in units but allow comparisons between students of different courses to form correlations with other indicators, such as academic performance. These indicators represent a useful approach to study usability and help to draw conclusions objectively. Table 1 shows the results obtained from five students, comparing questionnaire response averages with the usability index and each component.

The previous Table 1, shows that Student 122 obtained the highest usability score and highest average in his responses. Student 125, in contrast, had the worst average in his responses and thus the worst usability index. Hence, it appears that there is a direct relationship between the response means and the usability index assigned to each student.

C. *Academic performance assessment*

Because student achievement is unobservable or directly measurable, it is necessary to define it through an operational metric that allows us to find out what the student does or does not know.

In our case, the academic performance measurement is taken using a Relative Index (RI or IR) from school grades (POST-Test) as follows:

$$IR_i = \frac{N_i - NF_{ij}}{(NM_{ij} - NF_{ij})} \qquad (2)$$

TABLE II. PRE AND POST COURSE RESULTS

SUBGROUP/GROUP		PRE_Test	POST_Test	Gain
1M	***Mean (S.D.)***	2.52 (1.32)	4.24 (1.13)	1.72 (-0.19)
	N	26	26	
2M	***Mean (S.D.)***	3.14 (1.45)	4.36 (1.02)	1.22 (-0.43)
	N	44	44	
3T	***Mean (S.D.)***	2.66 (1.71)	4.80 (0.95)	2.14 (-0.76)
	N	38	38	
Control	***Mean (S.D.)***	2.82 (1.53)	4.49 (1.04)	1.67 (-0.49)
	N	108	108	
4T	***Mean (S.D.)***	2.62 (1.74)	4.81 (0.86)	2.19 (-0.88)
	N	38	38	
Experimental	***Mean***	2.62 (1.74)	4.81 (0.86)	2.19 (-0.88)
	N	38	38	
Total	***Mean (S.D.)***	2.77 (1.58)	4.57 (1.01)	1.80 (-0.57)
	N	146	146	0

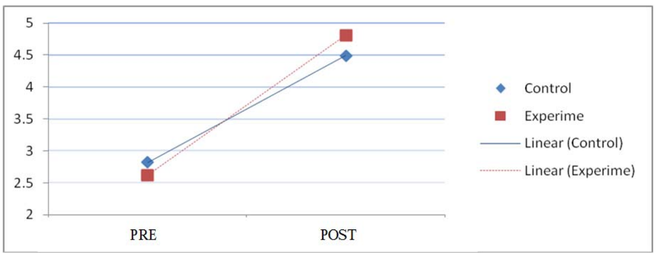

Fig. 5. Pre and Post results evolution

In the equation (2), R_i is the student rating in the subject i; N_i is the qualification (base 10) obtained by the student in the subject; NF_{ij} is the minimum qualification (base 10) of subject i in section j; and NM_{ij} is the maximum qualification (base 100) of subject i in section j. The student rating obtained was compared with the usability index and other variables that could be of interest.

In Fig. 5, the results show that the experimental group (4T) gets better results after training, which is 0.24 points above the mean of the control groups. The higher gain in relation to the average of the control groups is achieved by the experimental group. The table 2 shows, by groups and subgroups, the results and gains from the PRE to POST qualifications.

IV. Analysis and Discussion

To identify the most significant variables related to the overall course opinion, we correlated the students' final assessment with other variables. High correlations were detected with the following: the representativeness of the exercise (W_exercises = 0.74) and material presentation (W_material = 0.70).

These variables appear crucial to the success of this type of teaching assessment. However, variables related to being able to solve the exercises independently (W_learn_indep = -0.12) or previous knowledge of AR technology (AR_App = 0.07) did not correlate significantly with the students' global opinion of the course.

Furthermore, to evaluate performance improvement for small groups, we cannot strictly rely on the means of each group in the PRE and POST training. We used Student's t-distribution based analysis [31] to estimate the probability that groups were significantly similar in their PRE and POST qualification. We set the null hypothesis (H0) as no differences in scores between groups.

In the PRE-Test case, the statistical significance (2-tailed) was 0.502 (higher than 0.05), which means that there is a slight chance that the groups are different in their skills and previous training; therefore, the experimental group, who practiced with mobile devices, is very similar to the other groups. Therefore, the null hypothesis was accepted (no significant differences between groups).

The control and experimental group POST-Test qualifications were significantly different (Sig (2-tailed) = 0.097), which means that it is highly unlikely (approximately 10%) that the groups are coincident in their ratings. It is therefore reasonable to believe that there is a slight chance that students from the experimental group, who performed the exercise with mobile devices, also increased their final grade by completing the conventional exercise.

Finally (Table III), a correlation analysis was conducted between the academic performance, usability, and all other constructed indicators (1:Age; 2:Hours_Day; 3:Final_Assesm; 4:Knowledge; 5:Efficiency; 6:Effectiveness; 7:Satisfaction; 8:Usability; 9:Performance):

TABLE III. Correlations between performance, usability and other compound indicators

Correlation	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
(1)	1.00	0.27	0.06	-0.11	-0.15	0.28	0.22	0.14	0.27
(2)	0.27	1.00	0.63	0.51	0.39	0.55	0.75	0.63	0.01
(3)	0.06	0.63	1.00	0.41	0.67	0.77	0.77	0.84	-0.20
(4)	-0.11	0.51	0.41	1.00	0.33	0.21	0.44	0.37	-0.18
(5)	-0.15	0.39	0.67	0.33	1.00	0.60	0.54	0.82	-0.25
(6)	0.28	0.55	0.77	0.21	0.60	1.00	0.80	0.92	-0.12
(7)	0.22	0.75	0.77	0.44	0.54	0.80	1.00	0.89	0.01
(8)	0.14	0.63	0.84	0.37	0.82	0.92	0.89	1.00	-0.14
(9)	0.27	0.01	-0.2	-0.18	-0.25	-0.12	0.01	-0.14	1.00

As expected, the overall usability index correlates positively and significantly with effectiveness, efficiency and satisfaction. In addition, a high correlation (0.84) was found between the usability and the students' final assessment. These findings confirm the consistency of the indicator construction. Usability, as discussed, is related to the development of interactions with products that are easy to learn, effective and user-friendly from the user's perspective. Additionally, usability addresses the subjective perception of whether a system is good enough to meet all the needs and requirements of users, customers or managers [32].

However, the correlation between usability and academic performance was very weak and negative (-0.14). In other words, we cannot ensure that a student who shows a high degree of satisfaction with the course (useful, bug free, etc.) will achieve better results than one that scored worse on these variables.

V. Conclusions

In relation to the first research question, we may say that the outcomes obtained from the questionnaires were extremely positive. The overall assessments regarding efficiency, effectiveness and satisfaction were all approximately 3.5 points out of 5. Therefore, we can affirm that students felt satisfied and motivated using this new methodology. In addition, the exercise representativeness and material presentation appear to be crucial to the success of this type of teaching technique. Conversely, variables related to being able to solve the exercises independently did not correlate significantly with the course's final assessment.

As pertaining to the second research question, the results showed how AR technology can help improve academic performance by increasing student motivation. Student's t-test analysis confirmed that all groups were significantly similar in previous training. Once the course was finished, the experimental group achieved the best gain and performance results. We tested these strategies in previous case studies [33] and similar results were found. In all of these studies, students felt active and motivated. The students engaged, participated, and interacted with 3D virtual content, and their learning, therefore, was maximized. A weak significance was found between groups; thus, there is a slight chance that students who completed the exercise with mobile devices also increased their final qualification by completing the conventional exercise.

However, as related to the third research question, no significant correlation was found between the system usability and the students' academic performance. Accordingly, while students from the experimental group achieved better overall gain results, individually, students with the best academic results did not respond with the highest usability ratings.

Finally, the AR technology using mobile phones on building construction areas offers the opportunity of visualizing different stages of a constructive process "on site", helping to improve its understanding. This fact allows verifying and comparing different scenarios and virtual proposals prior to real construction. This technology could replace real interventions. To do so, the ability of viewing different models with the same marker is extremely important to show different layers, models, etc., thereby simulating an actual constructive process.

As a future research line, we must emphasize 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 us (descriptive, predictive or casual questions, that differentiates research problems.). These studies are typical examples of studies that generate incomplete data [34-35], and they lack detail and are missing variables because of the initial design flaws. This lack of accuracy is due to the teachers' inadequate pre-selection 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 [36]. The possibility of biased results provides us with a starting point, previously used in academic fields close to ours [37], allowing us to approach the experiment with a mixed methodology and benefit from different data analysis methods. Using complementary qualitative research, we can obtain new variables to study in future iterations and more detail for the quantitative data. Meanwhile, thanks to the quantitative data, we can minimize the primary problems of the qualitative research: subjectivity and no generalization [38].

The present academic year (2013-14), we are conducting similar case studies in different subjects related with the Building Engineering, Architecture and Multimedia degrees. In all cases, we are using AR and VR to discuss about complex 3D models using mobile devices in the classroom. In all cases, we will use a mixed-method to evaluate the motivation, satisfaction and academic performance of our students. The new methodology is both quantitative (through a structured test) and qualitative (using the Bipolar Laddering, BLA [39]), and it is based in the use of Augmented Reality (AR) to present, visualize and discuss 3D models realized using CAD tools (Computer Assisted Design).

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 is to ascertain which concrete characteristic of the product entails users' frustration, confidence or gratitude (between many others). 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 is 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

This new proposal has been used previously and has demonstrated its usefulness as a dynamic system for capturing information related to students' experiences with technological elements in education [40]. 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 us to obtain additional information from the quantitative variables that would otherwise have not been achievable.

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