RUSC Revista de Universidad y Sociedad del Conocimiento
Universities and Knowledge Society Journal
http://rusc.uoc.edu

Special Section "Mobile Learning Applications in Higher Education"

ARTICLE

Mobile learning in the field of Architecture and Building Construction. A case study analysis

Ernest Redondo Domínguez
ernesto.redondo@upc.edu
Doctor of Architecture, Tenured University Lecturer,
Department of Architectural Representation and Visual Analysis I, Barcelona School of Architecture (ETSAB),
Universitat Politècnica de Catalunya-BarcelonaTech (UPC), Spain

David Fonseca Escudero
fonsi@salle.url.edu
Doctor of Engineering, Tenured University School Lecturer, Department of Architecture,
La Salle Campus Barcelona, Ramon Llull University (URL), Spain

Albert Sánchez Riera
albert.sanchez.riera@upc.edu
Doctor of Architecture, Assistant Lecturer, Department of Architectural Representation and Visual Analysis II,
Barcelona School of Architecture (ETSAB),
Universitat Politècnica de Catalunya-BarcelonaTech (UPC), Spain

Isidro Navarro Delgado
isidro.navarro@upc.edu
Architect, Doctoral Student, Department of Architectural Representation and Visual Analysis I,
Barcelona School of Architecture (ETSAB),
Universitat Politècnica de Catalunya-BarcelonaTech (UPC), Spain

Submitted in: May 2013
Accepted in: October 2013
Published in: January 2014

Recommended citation

Redondo, E., Fonseca, D., Sánchez, A. & Navarro, I. (2014). Mobile learning in the field of Architecture and Building Construction. A case study analysis. Mobile Learning Applications in Higher Education [Special Section]. *Revista de Universidad y Sociedad del Conocimiento (RUSC)*. Vol. 11, No 1. pp. 152-174. doi http://dx.doi.org/10.7238/rusc.v11i1.1844

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

Abstract
This educational research focuses on the use of mobile learning (m-learning) in the field of Architecture and Building Construction. It was conducted at various levels of university teaching (bachelor's and master's degree courses) to assess the integration of augmented reality (AR) technology on mobile devices. Several cases employing different strategies were studied. These strategies ranged from using Quick Response (QR) codes or specific markers to download multimedia content created by the students, to 3D georeferencing models that allowed information to be visualised, adjusted and assessed on site. Specific practical exercises were therefore designed for different topics, where the two most common forms of registering were tested (optical image recognition and GPS positioning). Light integration at the scene was also addressed. Owing to the high cost and limited availability of these devices, experimental groups made up of small numbers of students were formed so that devices could be shared if necessary. Improvement in academic performance and system usability were assessed in each specific case using standardised questionnaires, and the results were compared to those obtained for the control group students. The results show that these devices have become an effective, efficient and satisfactory tool for the use of hand-held AR technology.

Keywords
educational research, mobile learning, augmented reality, architectural representation, user experience

Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

Resumen
*En esta investigación educativa nos hemos centrado en el uso del aprendizaje móvil (ML) en el campo de la arquitectura y la construcción. Se llevó a cabo en distintos niveles de la enseñanza universitaria de grado y de máster, a fin de evaluar la integración de la tecnología de la Realidad Aumentada (RA) en dispositivos móviles. Se han realizado varios estudios de caso, en los que se han abordado diferentes estrategias, que van desde el uso de los códigos QR (*quick reference*) o marcadores específicos para descargar contenidos multimedia generados por los estudiantes tales como los modelos 3D georeferenciados para ser ajustados y evaluados en el lugar. Por lo tanto, se diseñaron prácticas específicas en el marco de diferentes temas, donde los dos tipos más comunes de registro han sido probados (reconocimiento óptico de imagen y posicionamiento GPS). También se ha abordado la integración de la luz en la escena. Debido al alto costo y a la disponibilidad limitada de estos dispositivos, hemos creado grupos experimentales con pocos alumnos que comparten, si es necesario, los terminales. La mejora del rendimiento académico y la manejabilidad de los sistemas han sido evaluadas en cada caso específico utilizando cuestionarios estandarizados, en comparación con el grupo de estudiantes de control. Los resultados muestran que estos dispositivos se han convertido en una herramienta eficaz, eficiente y satisfactoria para el uso de esta tecnología móvil, la RA en su versión (*hand-held*) manejable a mano.*

Palabras clave
investigación educativa, aprendizaje móvil y realidad aumentada, representación arquitectónica, experiencia de usuario

1. Introduction

The experience presented in this article did not take the format of a traditional subject, but instead used specific technologies such as augmented reality (AR) in workshops, or mobile learning (m-learning) modules, integrated into various subjects in the field of Architecture and Building Construction Science and Technology. In these workshops, specific applications (apps) and practices were used to visualise virtual models at real scenes on mobile phones and tablets, incorporated at particular times during bachelor's and master's degree courses. In accordance with the proposed model, those students with advanced mobile devices formed part of the experimental groups (EGs or scenario S2), and they visualised virtual content that they had mostly created themselves at a specific place. The remaining students doing the ordinary workshop formed part of the control group (CG or scenario S1).

The strategy had been designed as an independent module for the visual assessment of projects or construction details on site. The hypothesis tested was whether it contributed new values to the learning process by involving the students in the creation, visualisation and adjustment of virtual architectural models as a step prior to their construction, providing close-up topical knowledge and the opportunity for the students to interact with those models by sharing their ideas about the site. All of this allows the students to take part in their educational processes while using devices and technologies that motivate them because they form part of their natural environment. The comparison between attaining the general subject objectives of the two groups (EG and CG) and the potential improvement in academic performance of the EGs assessed as case studies was the basis of the project presented here.

These practices were applied to subjects across the bachelor's degree courses in Architecture of the Barcelona School of Architecture (ETSAB) at the Universitat Politècnica de Catalunya-BarcelonaTech (UPC) and in Building Construction Science and Technology of the Barcelona School of Building Construction (EPSEB) at the UPC, the university master's degree course in Urban Management and Valuation at the UPC, and the bachelor's degree courses in Architecture and Building Construction Science and Technology of the La Salle Campus Barcelona at Ramon Llull University (URL). In this field, AR m-learning was trialled using technologies ranging from QR codes to visualise and download multimedia content, to positioning (registering) virtual models in the environment (by optical image recognition or geolocation).

The experience was based on the hypothesis that the new information and communication technology (ICT) tools used in the Web 3.0 environment enable the students' skills (Álvarez, 2012) and learning processes (Álvarez & Bassa, 2013) to be improved at a lower cost (using free applications or educational licenses) and in less time. Furthermore, all of that can be done without any prior experience thanks to the intuitive touch-screen interfaces of the latest-generation mobile devices. In combination with the advances in cloud-computing (CC) technology, which enables apps and services to be shared ubiquitously on the Internet, a workflow is generated that allows the teaching experience using AR m-learning to become a new paradigm of continuing education and contextual self-study.

Several strategies were used to test the hypotheses, starting with a pre-test, which established the technological profiles of the students and their own knowledge of technology, which in turn determined the EG. Questionnaires were then used to find out about the usability of the methods and processes considered. Parameters to assess academic performance on completion of the experiences were included in the post-test. Besides being more motivated by the designed experiments, the EG students generally achieved better results in their academic performance, which, in the absence of more in-depth testing, relates the correct use of these technologies to the students' curricular improvement.

2. Objetives

As already mentioned, the aim of this research was to assess hand-held AR technology in learning processes. First, the usability of the systems employed and, second, the improvement in the students' academic performance were assessed. This assessment was based on the study of person/mobile device interaction in teaching processes (Argüelles, Callejo, & Farrero, 2013), and on the ability to visualise virtual models or make digital notes and sketches using devices of this type. These aspects are what we would consider to be today's version of architectural photomontage, seeking to foster greater interest in the disciplines involved in order to bring about an improvement in the students' academic performance.

In order to implement these experiences, content and specific assessment methods were developed regarding the use of mobile devices to visualise content locally and ubiquitously, and of commercial (ARmedia©, Layar©) own-developed apps designed by the workgroup for free distribution and use on the Android© operating system. The latter app, called U-AR, was considered necessary to enable the creation and personalised management of virtual content using AR, which, in the field of study in question, has a number of potential advantages over those already in the marketplace (Sánchez Riera, Redondo, & Fonseca, 2012).

The specific objectives of each experience focused on assessing whether there were significant differences in (a) the academic results and (b) the students' levels of satisfaction and motivation depending on the teaching scenario used (S1, based on conventional methods, and S2, based on AR m-learning). To that end, the following research questions were posed: (Q1) Are there any differences in the students' levels of satisfaction and motivation depending on which of the two proposed teaching scenarios is used?, and (Q2) Are there any differences in the academic results depending on which of the two proposed teaching scenarios is used?

3. Background

The first works on m-learning were by Kristoffersen and Ljungberg (2000). Other experiences (Lehner & Nosekabel, 2002) extended the idea into an Internet and mobile device-based virtual university

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

by developing an m-learning platform called Welcome. Several authors (Prahalad & Hamel, 1990) have called for this educational competency to be considered basic, and it has been expanded in our experiences (Fonseca et al., 2013), where we would effectively be talking about a concept midway between m-learning and ubiquitous learning (u-learning), in which data are stored in the cloud. In view of these references and the lack of others, especially in the architecture and building construction environment, we considered it worthwhile to further this educational research. Regarding AR technology, many studies have been done on its potential: in medicine (Paiva, Machado, & Oliveira, 2012), in maintenance or assembly operations (Benbelkacem et al., 2009; Hincapie et al., 2011), in tourism (Guttentag, 2010; Hsu, 2011), in museums (Tillon, Marchal, & Houlier, 2011) or in advertising and marketing (Honken et al., 2012), as well as in areas that are more closely-related, such as archaeology and historical heritage (Haydar et al., 2008), planning and urbanism or construction and maintenance processes (Allen, Regenbrecht, & Abbott, 2011).

Some authors have suggested the viability of introducing AR into other areas such as design, excavation, layout, inspection, the coordination or supervision of tasks (Shin & Dunston, 2008), or infrastructure visualisation (Schall et al., 2008). In building restoration, it has been trialled, using mobile devices, to visualise the final appearance of a site on a 1:1 scale (Tonn et al., 2008). Its usefulness as a tool for representing internal spaces has also been tested (Wang, 2008) by experimenting with apps that did not require any prior experience (Oksman, Siltanen, & Ainasoja, 2012). In the educational environment, its usefulness has been demonstrated for improving mathematics teaching (Kondo, 2006), spatial abilities (Martín Gutiérrez, 2010) or music (Peula et al., 2007). Edutainment (education+entertainment) proposals such as Construct3D have been studied (Kaufmann, Schmalstieg, & Wagner, 2000), and there are websites that offer students the chance to buy augmented books to improve their skills (Martin et al., 2011).

4. Method

4.1. Assessment of the usability of the systems employed

We used online and paper-based questionnaires that had generally been designed with two objectives in mind: to assess a specific element and to obtain qualitative feedback from the students. Generally, the questions had been designed to be answered using Likert scales, where 1=disagree and 5=strongly agree. The results were analysed for each of the workshops done, and were then processed jointly. Each questionnaire was divided into four sections (A, B, C and D) in accordance with the following descriptions: A: personal questions about gender, age, name, qualifications, etc.; B: questions about prior knowledge of the technology, which were useful to evaluate the students' technical profiles; C: opinion of the workshop and the teaching materials used; and D: opinion of the AR m-learning and 3D object-modelling technology.

The answers obtained served as the basis for the analysis based on ISO 9241-11, which sets out guidelines for usability in relation to three principal components: effectiveness, understood as the user's ability to complete tasks during the workshop, in relation to accuracy and integrity; efficiency, understood as the allocated resources, with questions about time and effort spent on resolving the proposed exercises; and satisfaction, understood as the students' subjective reactions to the workshop. Especially noteworthy was the exercise in which Layar was used (case study 3), where the opportunity to answer certain geolocated questions was incorporated into the on-site visualisation process, which enabled an assessment of the students' opinions of how the different proposals had been integrated into the site. The only format used was Google Docs, which allowed the results to be gathered and analysed immediately (Figure 1).

Figure 1.

4.2. Improvement in academic performance

A crucial aspect was the curricular assessment of the students who had used such technologies in order to check whether their performance had improved in comparison to those who had not used them. To that end, it was necessary to compare their scores in the pre-test and compare them with the scores that they obtained after doing the workshop (post-test). The students were divided into two groups, EG (using AR) and CG (doing a conventional workshop). As the groups were small, we could not strictly take the means of each group, but instead had to estimate the probability of the groups being convergent before and after doing the workshop (pre-test and post-test). For that purpose, the statistical procedure developed by Gosset (1908) was used, which is known as Student's t-test and is suitable for making precise estimates from data with small samples. In order to check if the groups were initially similar, that is to say, if the variation in scores (pre-test) between the different groups was not significantly greater than the variation within the groups, an analysis of variance (ANOVA) was performed, which allowed the null hypothesis (h0) of convergent scores in the different

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

groups (no differences) to be tested. The flow diagram used to assess performance is shown below (Figure 2).

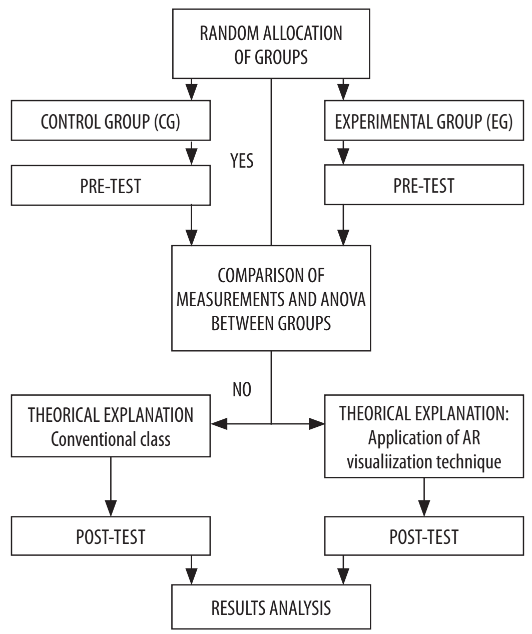

Figure 2.

5. Case Studies

The students in the EG were given specific AR training. The specifically designed workshops lasted for six hours, and were divided into three two-hour sessions. The first session was for the students to receive generic training on how to use and manage the AR apps that would be employed. The second session was for the students to practise how to visualise the imported models and how to interact with the specific players (U-AR, ARPlayer and Layar). The third outdoor session was for the students to experiment on site with the fit of the virtual models, assessing both the model and the experience. Table 1 shows the different case studies conducted. Only cases 3 to 6 (with a bold border) are described below because the most distinct variants of AR technologies were used in them. These cases represented the end of the preliminary study phase (cases 3 and 4) and the start of the assessment and usability of the app created for such purposes (5 and 6)..

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

Table 1

PHASES	EXERCISES		ENVIRONMENT	REGISTER	MARKER	SOFTWARE	HARDWARE	ASSESSMENT
0. FEASIBILITY STUDY	0 GIRONELLA		Outdoor	OPTICAL	AR_toollkit / img	AR_Media / JUNAIO	Lap Top./ Mobile	Feasibility
1. PRELIMINARY STUDIES USING EXISTING SOFTWARE AND PLATFORMS	1 BEST	1.1 1.2 1.3	Indoor Indoor Outdoor	OPTICAL	AR_toollkit img	AR_Media / Build AR / JUNAIO	Lap Top./ Mobile	Usability
	2 DAC		Indoor		AR_toollkit	AR_Media	Lap Top	Usability
	3 EGIII		Indoor		AR_toollkit	AR_Media	Lap Top	Usability
	4 TICS (layar)		Outdoor	GPS	---	LAYAR	Mobile	Usability
2. OWN DEVELOPED APP	5 APF		Outdoor	OPTICAL	Img.	U-AR	Mobile	Usab / Performance
	6 PT II		Indoor			U-AR	Mobile I	Usab / Performance

5.1. Case study 1

Information Technology (IT) Applications (APF) (3 credits), Architecture at ETSAB-UPC, 2012. The objective of the subject was to model urban units, squares or stretches of streets and to develop urban design projects in them by incorporating sculptural elements. This process involved two thematic areas: digital image processing and the use of responsive tools to create virtual 3D scenes. In this case, we focused on the study of interventions in the urban landscape of Barcelona; the place of intervention was Flassaders square and the reference model was sculptures. The work group comprised 25 students divided into 3 groups: a CG (8 students) without 3G phones doing the

Figure 3.

conventional workshop, and two EGs using iOS (9 students) and Android (8 students) devices, who were given specific training on how to use the specific AR. Android users used the own-developed U-AR app and iPhone© users used ARmedia© (Figure 3).

The objective of the EG focused on assessing the best fit in terms of size and location of the models in relation to the dimensions of the square. This basic aspect of the exercise was corroborated, as the CG students made disproportionate proposals in comparison to the EG students, whose properly adjusted the size of their proposals (Redondo et al., 2012).

5.2. Case study 2

Technical Projects II, (PT II) (3 credits), Building Construction Science and Technology at EPSEB-UPC, 2012. The object of study focused on the application of ICTs to construction and maintenance processes. The exercise focused on visualising the construction process of a load-bearing wall support. A total of 146 students took part in this experience, who were divided into 3 CGs and 1 EG (Figure 4). Details of the experiment are described in Sánchez et al. (2013).

Figure 4.

5.3. Case study 3

ICTs Applied to Territorial Analysis (TICS) (60 hours), university master's degree course in Urban Management and Valuation, ETSAB-UPC, 2012. The topic of the experiment focused on the Barcelona Knowledge Campus (BKC). A total of 11 students took part in this experiment, in a single EG. Use was made of a geographical information system (GIS) capable of integrating the data obtained (digitally modelled buildings located in their real, physical coordinates) in a georeferenced manner. In this case, Layar© was used. It is a free app that allows both alphanumeric and digital-model content to be georeferenced for their integrated visualisation on mobile devices (Figure 5). Details of the experiment are described in Redondo et al. (2013).

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

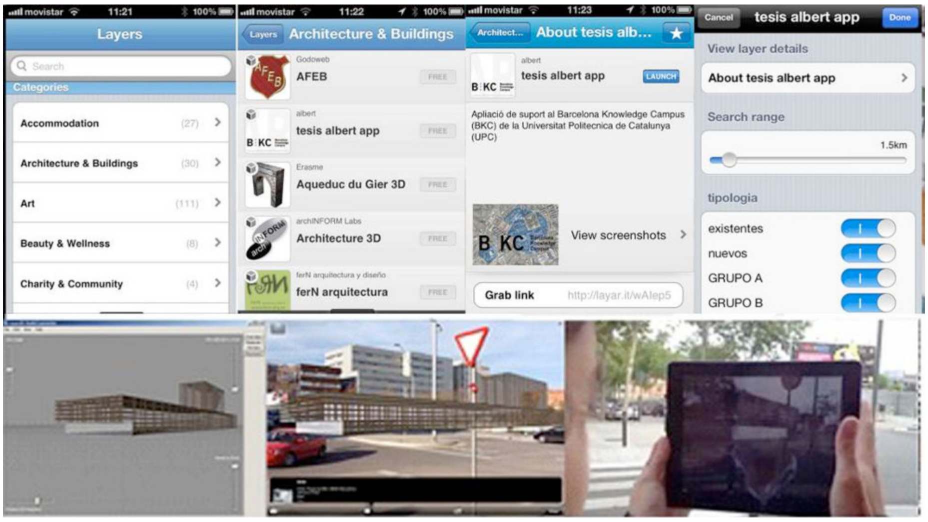

Figure 5.

5.4. Case study 4

Representation Systems II (EG III) (9 credits), Architecture at La Salle Campus Barcelona, URL, 2011/2012. A total of 57 students did the project. The students on the previous workshop were taken as the CG. All of the students had been given CAD 2D and 3D training. In this case, integrated use was made of several AR m-learning strategies to present the projects, using QR codes linking to multimedia content: videos, CAD, virtual 3D models integrated into AR, specific websites, etc. (Figure 6). Details of the surveys and academic progress are described in Fonseca et al. (2012).

Figure 6.

RUSC Revista de Universidad y Sociedad del Conocimiento
Universities and Knowledge Society Journal

6. Results Analysis

6.1. Usability

The joint results of the four workshops assessed in this instance, where each variable had the same weight in the formation of the indicator that it explained, are given in Figure 7 below, which shows the mean results of the workshops done in relation to effectiveness, efficiency and level of satisfaction reached. It is possible to observe that the three components forming part of usability obtained similar ratings, at around 3.5 out of 5 points, with satisfaction higher than the rest.

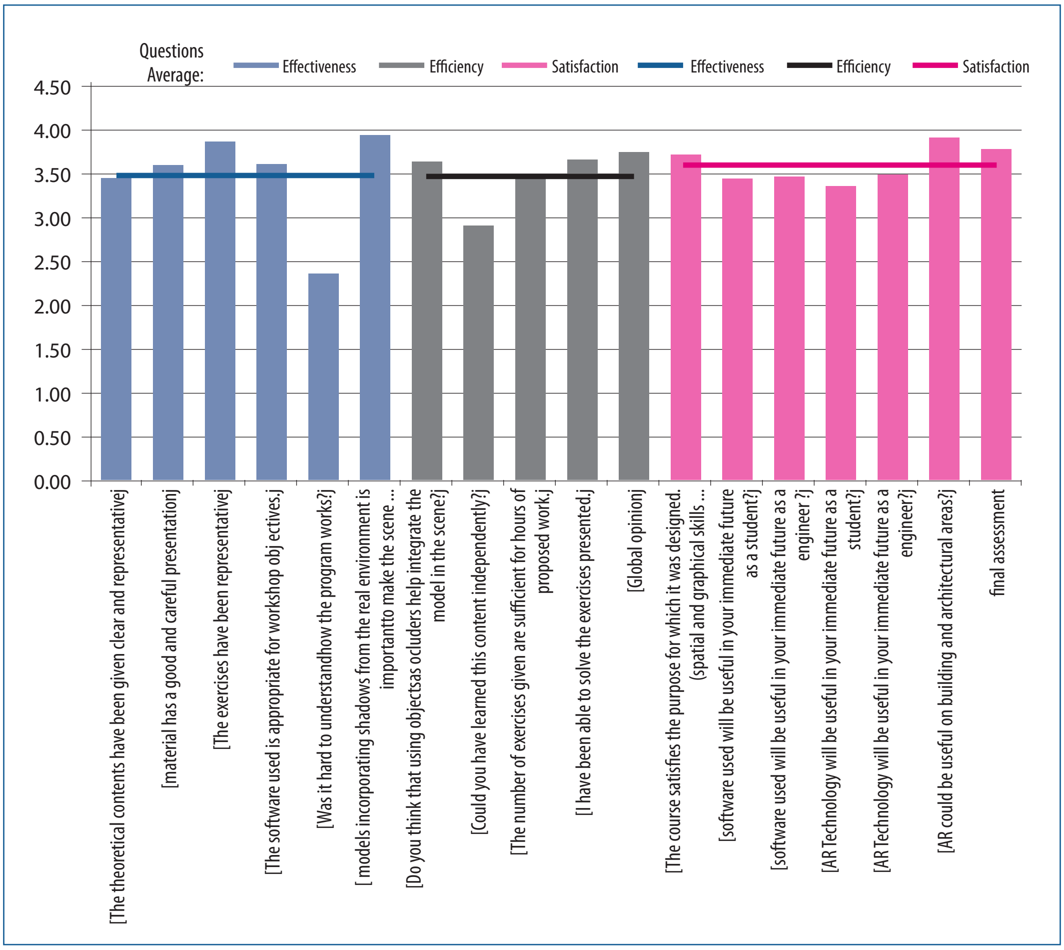

Figure 7.

However, some questions that ought to be posed are (a) How do each of these indicators relate to each other?, (b) What relationship is there between these usability components and usability itself?, and (c) What relationship is there between each of them and other variables such as the final rating, the number of hours that the student used a computer, or performance, if it was assessed? To answer these questions, compound indicators were constructed (which we have called Level II). Used for that purpose was the analysis of principal components extracted from the group of original single indicators that would form part of each indicator. Based on their values and percentages of variance explained, each compound index was constructed in accordance with the following formula:

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

An equation to construct the quality indicator on the basis of each component and its eigenvalues, according to Peters and Butler (1970), where: Imj represents the compound indicator to be obtained (efficiency, satisfaction, effectiveness, etc.) for each j-th student; Zrj is the score of the r-th component (factor) for the j-th student; and √y, is the square root of the eigenvalue for that component. This therefore ensured that the components with a higher variance explained had greater weight in the rating of the new variable being derived. After obtaining the index, it was normalised on a scale from 0 to 1. The value obtained illustrated each student's situation in comparison to that of the other participants in the questionnaire for each of these indices. Thus, the following variables were constructed: level of education, efficiency, effectiveness, satisfaction and usability. Table 2 shows a summary of usability assessment results obtained from the various experiments.

Table 2

		BEST	DAC	EG III	TICS	APF	PT_II
Prior knowledge of technology	[LINUX-UNIX OS]	0.59	0.10	1.22	1.27	1.00	1.26
	[WINDOWS OS]	2.29	2.71	4.19	4.36	4.00	4.31
	[Macintosh OS]	0.76	1.67	1.57	2.00	2.00	2.14
	[Word Processors]	1.76	1.86	3.78	3.73	3.33	3.71
	[Spreadsheets]	1.76	1.29	3.19	2.82	2.33	3.46
	[Databases]	1.29	1.62	2.35	2.73	2.17	2.80
	(GIS)	0.82	0.43	1.86	1.64	1.33	2.09
	[Photo editing]	1.59	1.86	2.68	2.91	3.50	3.06
	(CAD)	1.59	2.90	3.76	4.00	3.83	4.00
	[Multimedia Applications]	1.65	1.14	2.86	3.55	3.50	3.11
	[Internet browsers and search engines]	2.59	2.24	4.22	3.91	3.67	3.97
	[Email Software]	2.59	2.95	4.38	4.27	3.67	4.29
	[AR Applications]	0.71	0.19	0.24	1.00	1.83	2.06

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

		BEST	DAC	EG III	TICS	APF	PT_II
Workshop opinion	[The theoretical contents have been given clear and representative]	-	-	3.62	3.73	3.67	3.17
	[material has a good and careful presentation]	4.18	3.52	3.70	3.64	3.50	3.34
	[The exercises have been representative]	4.53	4.05	3.97	3.91	3.50	3.49
	[The software used is appropriate for workshop objectives.]	4.00	3.76	3.92	3.09	3.50	3.29
	[The course satisfies the purpose for which it was designed. (New Graphical tools for presentations)]	4.35	3.86	3.76	3.73	3.83	3.31
	[Could you have learned this content independently?]	2.88	2.57	2.89	2.82	1.83	3.37
	[The number of exercises given is sufficient for hours of proposed work.]	4.18	3.62	3.41	3.18	3.50	3.17
	[I have been able to solve the exercises presented.]	4.18	3.57	3.76	3.64	3.33	3.54
	[Global opinion]	4.07	3.62	3.86	4.00	4.17	3.46
3D modelling and augmented reality	[Prior knowledge of the use of modeling software?]	-	2.95	2.41	2.27	-	-
	[Prior knowledge of the use of AR on mobile devices	-	1.24	1.22	1.18	1.00	2.03
	[Was it hard to understand how the program works?]	-	2.71	2.24	2.00	2.67	2.40
	[Software used will be useful in your immediate future as a student?]	-	3.67	3.38	3.73	3.50	3.37
	[Software used will be useful in your immediate future as an engineer?]	-	3.81	3.32	3.64	4.00	3.34
	[AR Technology will be useful in your immediate future as a student?]	-	3.86	3.11	3.45	3.50	3.31
	[AR Technology will be useful in your immediate future as an engineer?]	-	3.90	3.27	3.36	3.83	3.54
	[AR could be useful on building and architectural areas?]	-	4.10	3.84	4.09	4.00	3.83
	[Models incorporating shadows from the real environment is important to make the scene more realistic?]	-	4.29	4.03	3.27	4.33	3.89
	[Do you think that using objects as occluders help integrate the model in the scene?]	-	-	3.84	3.55	3.50	3.57
	Final assessment	4.18	3.67	3.78	4.27	3.83	3.51

Focusing specifically on the students' assessments and their relationship with potential curricular improvements, as an example we would point out that student 122 (see Table 3) had the highest score and mean in his/her ratings. In contrast, student 125 had the lowest mean in his/her answers and consequently the lowest rating, which would suggest the potential existence of a direct relationship between the answer mean and the usability index assigned to each student. However, student 48, with a mean identical to the previous student, did not have a zero rating, but rather slightly above. Similarly, taking into account only the mean of his/her answers, student 67 had the second highest result. However, he/she had a lower usability index than student 41, who, with a lower answer mean, had a higher usability index, due basically to a higher overall consideration of efficiency, effectiveness and level of satisfaction shown. In other words, while student 41 was less satisfied with the workshop done, he/she considered it to be efficient and effective, and more so than student 67, who gave it a higher score than the other students. Thus, the constructed index served to correlate other variables such as academic performance, which was not directly related to the answer mean, as it was derived from the indicators explaining a higher percentage of the latter. In this section, the comparison of all the experiments undertaken is shown in the table below.

Table 3

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
Mean	**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**

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

6.2. Improvement in academic performance

As already mentioned, on completion of workshops APF and PT II, the students submitted proposals for assessment by the lecturers. By way of an example, Table 4 below shows, by group and sub-group, the results and gains obtained in the pre-test and post-test workshop measurements for Technical Projects II (PT II), which had the highest number of students and from which the most relevant conclusions could be drawn.

Table 4

SUB-GROUP/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**

The results show that the EG (4T) had a higher score (4.81) after training (post-test), which was 0.24 points above the CG mean (4.49). In addition, they show a greater gain in comparison to the CG mean (Figure 8).

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

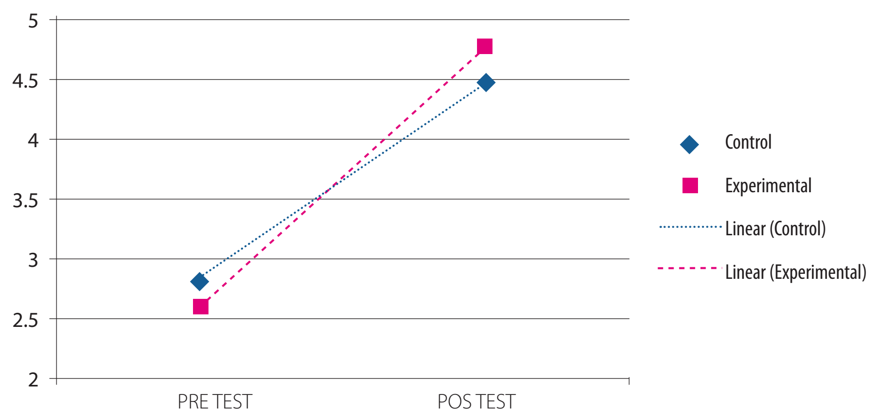

Figure 8.

7. General Conclusions

Regarding the questions posed at the start of this experience, it should be noted that significant differences were found in all the workshops depending on the two scenarios considered. In the EG, these were reflected in both the students' motivation levels and improvement in their academic performance. Thus, the results obtained show that the groups using the new method (AR m-learning) secured an improvement in their scores. Obtained from the post-test assessment, these scores show the greatest gain in comparison to the pre-test done at the start of the workshop. Likewise, and according to the data, comparable in the surveys carried out, the experience generated a high degree of expectation among the students, which led to greater motivation and engagement while the workshop was being done. These students had high scores for materials, workshop content and the method used, which would suggest that this technology could be effective in learning processes as a complement to conventional training..

Regarding the relationships between the variables that had an impact on the global opinion of the workshop, the correlations obtained were not particularly high compared to the rest of the workshops. Those for presentation quality and exercise representativeness had the clearest relationships (0.70 and 0.73, respectively). In contrast, the variables for prior knowledge of the technology and use of software and operating systems did not significantly correlate with the global opinion of the workshop. Finally, we can assert that AR m-learning technology to visualise architectural projects of all kinds has great potential, be it for visualising their scale on site, their appearance or the different stages of execution, and contributes to a better understanding and communication of them. This allows different virtual proposals to be checked and compared before they are built for real. Given all of the above, we consider that this educational experience has contributed new pedagogical values that have allowed already consolidated content and methodologies to be developed, and that such values have had a direct impact on Architecture and Building Construction studies. As a future line

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

of work, we are developing new questionnaires to incorporate qualitative aspects based on personal interviews.

Acknowledgments. Funded project. VI National Plan for Non-Oriented Fundamental Research, 2008-2011, Government of Spain. EDU-2012-37247/EDUC.

Referencces

Álvarez, G. (2012). New Technologies in the University Context: The Use of Blogs for Developing Students' Reading and Writing Skills. *RUSC. Universities and Knowledge Society Journal*, *9*(2), 3-17 | 185-199. doi:10.7238/rusc.v9i2.1160

Álvarez, G., & Bassa, L. (2013). ICTs and collaborative learning: a case study of a class blog for improving the writing skills of pre-university students. *RUSC. Universities and Knowledge Society Journal*, *10*(2), 5-19 | 254-268. doi:10.7238/rusc.v10i2.1740

Allen, M., Regenbrecht, H., & Abbott, M. (2011). Smart-phone augmented reality for public participation in urban planning. *Proceedings of the 23rd Australian Computer-Human Interaction Conference on - OzCHI'1*, 11-20. doi:10.1145/2071536.2071538

Argüelles, M. J., Blanco, M., & Castán, J. M. (2013). Dimensions of Perceived Service Quality in Higher Education Virtual Learning Environments. *RUSC. Universities and Knowledge Society Journal*, *10*(1) 89-106 | 268-285. doi:10.7238/rusc.v10i1.1411

Benbelkacem, S., Zenati-Henda, N, Belhocine, M., & Malek, S. (2009). Augmented Reality System for E-maintenance Application. *AIP Conference Proceedings, 1107*, 185-189. doi:10.1063/1.3106470

Fonseca, D., Martí, N., Navarro, I., Redondo, E., & Sanchez, A. (2012). Uso de la realidad aumentada como plataforma educativa en la visualización arquitectónica [Using augmented reality and education platform in architectural visualization: Evaluation of usability and student's level of satisfaction]. XIV Simposio Internacional de Informática Educativa. Andorra la Vella, Andorra: La Salle Open University, Eds. 1-6. Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6403157&isnumber=6403152

Fonseca, D., Martí, N., Redondo, E., Navarro, I., & Sánchez, A. (2013). Relationship between student profile, tool use, participation, and academic performance with the use of Augmented Reality technology for visualized architecture models. *Computers in Human Behavior*. doi:10.1016/j.chb.2013.03.006

Gosset, W. S. (1908). The Probable error of a mean. *Biometrika*, *6*(1), 1-25. doi:10.1093/biomet/6.1.1

Guttentag, A. (2010). Virtual reality: Applications and implications for tourism. *Tourism Management*, *31*(5), 637-651. doi:10.1016/j.tourman.2009.07.003

Haydar, M., Maidi, M., Rouseel, D., Mallem, M., Drap, P., Bale, K., & Chapman, P. (2008). Virtual Exploration of Underwater Archaeological Sites : Visualization and Interaction in Mixed Reality Environments. In K. R.-E. M. Ashley, S. Hermon & A. Proenca (Eds.). *Proceedings of VAST: International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage*, 141-148. doi:10.2312/VAST/VAST08/141-148

Hincapie, M., Caponio, A., Rios, H., & González, E. (2011). An introduction to Augmented Reality with applications in aeronautical maintenance. *2011 13th International Conference on Transparent Optical Networks,* 1-4. doi:10.1109/ICTON.2011.5970856

Honken, R., Jazz, K., Boudreau, Z., & Yearous, J. (2012). Building a sustainable mobile device strategy to meet the needs of various stakeholder groups. *Proceedings of the ACM SIGUCCS '12*, 41. doi:10.1145/2382456.2382466

Hsu, C. (2011). The Feasibility of Augmented Reality on Virtual Tourism Website. *2011 Fourth International Conference on Ubi-Media Computing,* 253-256. doi:10.1109/U-MEDIA.2011.66

Kaufmann, H., Schmalstieg, D., & Wagner, M. (2000). Construct3D: A Virtual Reality Application for Mathematics and Geometry Education. *Education and Information Technologies*, *5*(4), 263-276. doi:10.1023/A:1012049406877

Kondo, T. (2006). Augmented Learning Environment using Mixed Reality Technology. In T. Reeves & S. Yamashita (Eds.). *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2006* (pp. 83-87). Japan: AACE.

Kristoffersen, S., & Ljungberg, F. (1999). Mobile informatics. *ACM SIGCHI Bulletin*, *31*(1), 29-34. Retrieved from http://portal.acm.org/citation.cfm?doid=329671.329685.

Lehner, F., & Nosekabel, H. (2002). The role of mobile devices in E with a wireless E-Learning environment. In *Wireless and Mobile*. Retrieved from http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1039229.

Martín Gutiérrez, J. (2010). *Estudio y evaluación de contenidos didácticos en el desarrollo de las habilidades espaciales en el ámbito de la ingeniería* [Study and assessment of didactic content in the development of spatial abilities in the field of engineering] (Doctoral thesis). Universitat Politècnica de València, Valencia, Spain.

Martin, S., Díaz, G., Sancristobal, E., Gil, R., Castro, M., & Peire, J. (2011). New technology trends in education: Seven years of forecasts and convergence. *Computers & Education*, *57*(3), 1893-1906. doi:10.1016/j.compedu.2011.04.003

Oksman, V., Siltanen, S., & Ainasoja, M. (2012). User participation in co-creative services: Developing Virtual and Augmented Reality Tools for Do-it-Yourself Home Design. *Proceedings of the 16th International Academic MindTrek Conference on - MindTrek '12,* 229-230. doi:10.1145/2393132.2393181

Paiva, P. V. F., Machado, L. S., & Oliveira, J. C. de (2012). A Peer-to-Peer Multicast Architecture for Supporting Collaborative Virtual Environments (CVEs) in Medicine. *2012 14th Symposium on Virtual and Augmented Reality,* 165-173. doi:10.1109/SVR.2012.7.

Peters, W. S., & Butler, J. Q. (1970). The construction of regional economic indicators by principal components. *The Annals of Regional Science*, *4*(1), 1-14. doi:10.1007/BF01287726

Peula, J., Zumaquero, M., Urdiales. C., Barbancho, A., & Sandoval, F. (2007). Realidad aumentada aplicada a herramientas didácticas musicales. Grupo ISIS.

Prahalad, C.. & Hamel, G. (1990). The core competence of the corporation. *Harvard Business Review*, *68*(3), 9-91.

Redondo, E., Sánchez, A., Fonseca, D., & Peredo, A. (2103). Architectural Geo-E-Learning Geolocated Teaching in Urban Environments with Mobile Devices: A Case Study and Work in Progress (in press). In R. Shumaker (Ed.), *VAMR/HCII 2013, Proceedings, Part II,* LNCS 8022, (pp. 188-197). doi:10.1007/978-3-642-39420-1

Redondo Domínguez, E., Sánchez Riera, A., & Fonseca Escudero, D. (2012). Developing an augmented reality application in the framework of architecture degree. *Proceedings of the 2012 ACM Workshop on User experience in e-learning and augmented technologies in education – UXeLATE'12*, 37-42. doi:10.1145/2390895.2390905

Sánchez Riera, A., Redondo, E., & Fonseca, D. (2012). Developing an augmented reality application in the framework of architecture degree. *Proceedings of the 2012 ACM workshop on User experience in e-learning and augmented technologies in education – UXeLATE'12*, 37. doi:10.1145/2390895.2390905

Sánchez, A., Redondo, E., Fonseca, D., & Navarro, I. (2013). Construction processes using mobile augmented reality. A study case in Building Engineering degree. *Advances in Intelligent Systems and Computing*, *206*, 1053-1062. doi:10.1007/978-3-642-36981-0_100

Schall, G., Mendez, E., Kruijff, E., Veas, E., Junghanns, S., Reitinger, B., & Schmalstieg, D. (2008). Handheld Augmented Reality for underground infrastructure visualization. *Personal and Ubiquitous Computing*, *13*(4), 281-291. doi:10.1007/s00779-008-0204-5

Shin, D. H., & Dunston, P. S. (2008). Identification of application areas for Augmented Reality in industrial construction based on technology suitability. *Automation in Construction*, *17*(7), 882-894. doi:10.1016/j.autcon.2008.02.012

Tillon, A. B., Marchal, I., & Houlier, P. (2011). Mobile augmented reality in the museum: Can a lace-like technology take you closer to works of art? *2011 IEEE International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities,* 41-47. doi:10.1109/ISMAR-AMH.2011.6093655

Tonn, C., Petzold, F., Olivier B., Grundhofer, A., & Donath, D. (2008). Spatial Augmented Reality for Architecture – Designing and planning with and within existing buildings. *International Journal of Architectural Computing*, *6*(1), 41-58. doi:10.1260/147807708784640126

Wang, X. (2008). Implementation and Experimentation of a Mixed Reality Collaborative Design Space. In W. Shen, J. Yong, Y. Yang, J. Barthes, & J. Luo (Eds.). *Lecture Notes in Computer Science: Vol. 5236* (pp. 111-122). Berlin, Germany: Springer-Verlag.

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

About the Authors

Ernest Redondo Domínguez
ernesto.redondo@upc.edu
Doctor of Architecture, Tenured University Lecturer, Department of Architectural Representation and Visual Analysis I, Barcelona School of Architecture (ETSAB), Universitat Politècnica de Catalunya-BarcelonaTech (UPC), Spain

Architect (ETSAB-UPC, 1981). Doctorate in Architecture (1992). Doctorate special award (1994). Tenured university lecturer (1993), Department of Architectural Representation and Visual Analysis I (EGA-I), UPC. Department of EGA-I director (1996-2003). Deputy director of ETSAB-UPC (since 2011). He has two Government of Spain CNEAI-recognised six-year increments and two Government of Catalonia AGAUR-recognised research periods. Principal researcher on the National RD&I Project EDU-2012-37247/EDUC. Assessor of the Spanish National Agency for Quality Assessment and Accreditation. Assessor of the Spanish National Agency for Assessment and Foresight (since 2006). Director of the UPC research group in Architecture, Representation and Modelling (ARM). Director of the GILDA-ICE-UPC executive committee. Member of the scientific and editorial boards of several publications. Lecturer of several subjects in the field of Architectural Representation and Visual Analysis on the Architecture bachelor's degree course, using conventional and digital methods, and president of the final year project board at ETSAB-UPC and the Research into Urban Management and Valuation master's degree board, UPC (since 2008). Principal researcher on Educational Research Projects AGAUR, ICE-UPC, 1999ARCS-00230 and 2007MQD00025. Author of more than 25 indexed publications, WOK, SCOPUS, Avery, RIBA, focusing on the use of ICTs in architecture. He has supervised four doctoral theses.

Universitat Politècnica de Catalunya-BarcelonaTech
Av. Diagonal 649, 2
08028 Barcelona
Spain

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

David Fonseca Escudero
fonsi@salle.url.edu
Doctor of Engineering, Tenured University School Lecturer, Department of Architecture,
La Salle Campus Barcelona, Ramon Llull University (URL), Spain

Technical Engineer in Telecommunications (La Salle-URL, 1998). Bachelor's degree in Audiovisual Communication (Open University of Catalonia, UOC, 2006). Master's degree in Information and Knowledge Society (UOC, 2009). Doctorate (URL, 2011). Tenured university school lecturer (2002). Lecturer in the Department of Architecture, La Salle Campus Barcelona, URL (since 1997). Researcher for the Department of Media Technology, La Salle Campus Barcelona, URL (since 2005). Internationally certified by Autodesk in AutoCAD (since 1997) and Revit (since 2011). Project manager, Department of Architecture, La Salle Campus Barcelona, URL (since 2010): IntUBE (224286), OikodomosII (177090-LLP-1-2010-1-ES-ERASMUS-EAM), Repener (BIA2009-13365). He is a principal researcher on Project EDU-2012-37247/EDUC. Member of GILDA-ICE-UPC and of the scientific and editorial boards of several publications. Tutorial manager and academic tutor, lecturer of several subjects in the field of IT Tools on the bachelor's degree course in Architecture and Building Construction Science and Technology. President of final year work, final year project, final bachelor's degree and master's degree project boards at La Salle-UPC (since 1999). Member of several doctoral boards at the UPC and Pompeu Fabra University (UPF) (since 2011). Author of more than 10 indexed publications focusing on usability, accessibility and architectural education, as well as on the use of ICTs in architecture. He has jointly supervised two doctoral theses.

Universitat Ramon Llull
C/ Quatre Camins, 2
08022 Barcelona
Spain

Original title: Mobile learning *en el ámbito de la arquitectura y la edificación. Análisis de casos de estudio*

RUSC Revista de Universidad y Sociedad del Conocimiento
Universities and Knowledge Society Journal

Albert Sánchez Riera
albert.sanchez.riera@upc.edu
Doctor of Architecture, Assistant Lecturer, Department of Architectural Representation and Visual Analysis II, Barcelona School of Architecture (ETSAB), Universitat Politècnica de Catalunya-BarcelonaTech (UPC), Spain

Architect (Vallès School of Architecture (ETSAV), UPC, 1999). Postgraduate qualification in Executive Projects (UPC-Sert School, 2001). Postgraduate qualification in Town Planning and Land Management (Autonomous University of Barcelona (UAB)-APCE, 2005). Master's degree in Urban Management and Valuation (Centre for Land Policy and Valuations, UPC, 2010). Doctorate in Architecture (2013), with the thesis entitled *Evaluación de la tecnología de realidad aumentada móvil en entornos educativos del ámbito de la arquitectura y la edificación* (Assessment of augmented reality technology in educational environments in the field of architecture and building construction), focusing on the assessment of technology in teaching environments in the field of architecture, town planning and building construction.

Universitat Politècnica de Catalunya-BarcelonaTech
Av. Gregorio Marañón, 44-50
08028 Barcelona
Spain

Isidro Navarro Delgado
sidro.navarro@upc.edu
Architect, Doctoral Student, Department of Architectural Representation and Visual Analysis I,
Barcelona School of Architecture (ETSAB),
Universitat Politècnica de Catalunya-BarcelonaTech (UPC), Spain

Architect (ETSAB-UPC, 1999). Doctoral candidate on the Modelling and Visual Simulation in Architecture (MSVA) programme at ETSAB-UPC. Adjunct university lecturer (2005) in the Department of Representation and Visual Analysis I (EGA-I), UPC. Tenured university school lecturer in the Department of Architecture, La Salle Campus Barcelona, Ramon Llull University (URL) (since 1994). Internationally certified by Autodesk in AutoCAD (since 2010), MAX and Revit (since 2011). Member of the UPC research group in Architecture, Representation and Modelling (ARM). Member of the GILDA-ICE-UPC research group. Author of several indexed publications focusing on usability, accessibility and architectural education, as well as on the use of ICTs and augmented reality in architecture. Tutorial manager and academic tutor, lecturer of several subjects in the field of Architectural Representation and Visual Analysis, using conventional and digital methods, on the bachelor's degree course in Architecture and Building Construction Science and Technology. Training coordinator of BIM (Revit) parametric programs at the CAD Centre (CeCAD), La Salle (since 2010). Master's degree programme coordinator in the Department of Architecture, La Salle (since 2010). Director of the master's degree programme in Sustainable Architecture and Energy Efficiency (since 2009). Coordinator of the postgraduate programme in Environmental Architecture and Sustainable Town Planning (since 2009).

Universitat Politècnica de Catalunya-BarcelonaTech
Av. Diagonal 649, 2
08028 Barcelona
Spain