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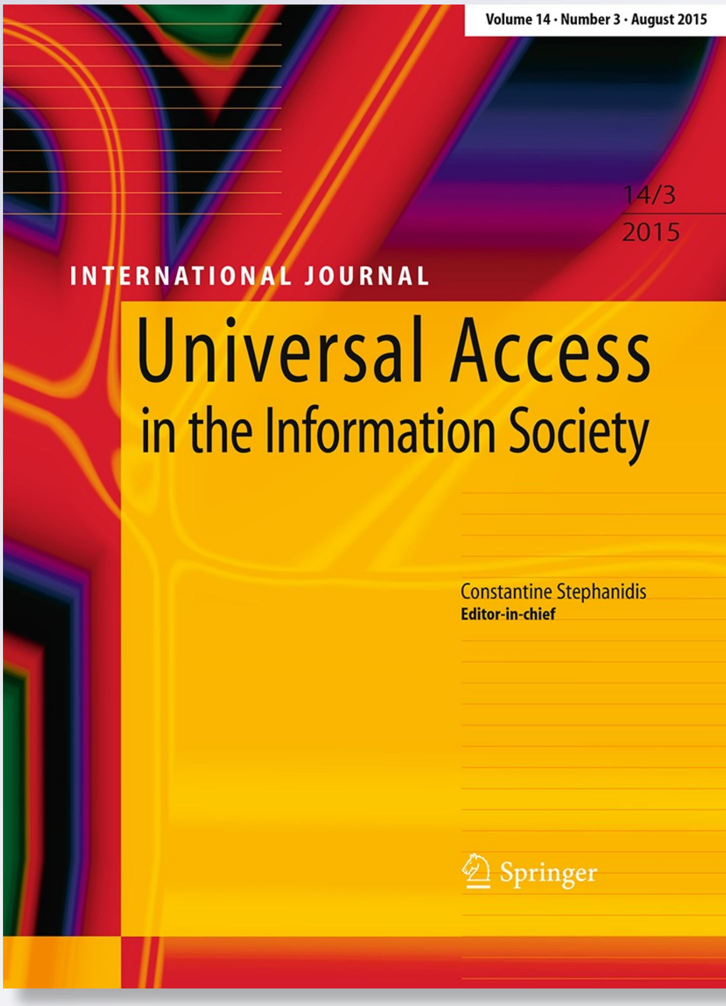


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LONG PAPER

# Geo-located teaching using handheld augmented reality: good practices to improve the motivation and qualifications of architecture students

Albert Sánchez Riera · Ernest Redondo · David Fonseca

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**Abstract** This work aims to evaluate the implementation of an augmented reality tool in the framework of architecture and building engineering education. It is based on a Geographical Positioning System to register virtual information on real space. Layar platform, for mobile devices, was used to visualize 3D models, which are linked to virtual information channels through a database and geo-located in their real position. The basis of this proposal is students' innate affinity with friendly digital devices such as smart phones or tablets. Educational content visualization in real environments was found to help students to evaluate and share their own-generated architectural proposals and improve their spatial skills. The suggested method aims to improve access to 3D multimedia content on mobile devices and adapt it to all types of users and content. In addition, a usability analysis was carried out to demonstrate the feasibility and effectiveness of this technology in educational settings.

**Keywords** User experience · Geo-learning · Augmented reality · Educational research · Design for all

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## 1 Introduction

Augmented Reality (AR) technology consists of overlapping virtual information in real space. A framework in which this technology could potentially be put to interesting use is the representation and management of the territory, because real scenes could be "completed" with virtual information. This method would facilitate a greater awareness and better understanding of the environment, especially if used in the educational area. In the field of architecture, for instance, AR makes possible the visualization of new building proposals and impact assessment on their planned site. To do that, a Geographic Information System (GIS) is needed to provide, manage, and filter public queries with different levels of accuracy and upgradeable information. In short, it is necessary to link a 3D model to a database that contains all the necessary information associated to it. This process was the first aim of this work [1].

The introduction of new learning methods using collaborative technologies, which help people involved in a common task to achieve goals, offers new opportunities to provide educational multimedia content. In the present case, AR is used to enhance a shared physical workspace and to create a common interface for three-dimensional computer-supported cooperative work (CSCW). Furthermore, new representation systems and management tools are becoming better known and easier to use, though this use does not involve a successful and correct implementation, suited to the educational needs of students.

The interest of educators in using new technologies in the teaching process presupposes a greater engagement and motivation on the part of students to understand content [2–4], leading to improve academic results [5]. To achieve these objectives, the methods proposed need to be designed and evaluated by teachers and students almost simultaneously, since during their implementation they usually do not take into account concepts such as "Design for All" or "Universal Access" that allow to adapt the content to a broader range of environments and users. The evaluation of a methodology focused on the training of architects and planners is the second objective of this investigation.

This proposal involves methodological changes that include information management through GIS, visualization using AR to enhance face-to-face and remote collaboration, and the interaction of many types of mobile devices, using free applications that support all these features, in this case, Layar© by SPRXmobile© (an application initially designed for tourism information). This platform was used because of its compatibility with all mobile operating systems and because the registration of virtual information is based on the use of Geographical Positioning System (GPS), which is accurate enough for outdoor environments.

The teaching experiences needed to validate the previous premises occur in Master's level subjects. They involve the application of information technologies (IT) to the analysis and territorial representation, where 3D GIS systems, 3D modeling, and urban virtual reality are combined. The proposed approach is based on the use of smartphones to incorporate virtual models generated by the students in an existing AR platform to view them on-site, through their own mobile devices.

The authors tried to promote new learning strategies for sharing, collaborating and transmitting information to other participants. In addition, this collaborative experience sought to make students aware of the importance of user/citizen opinions in the design phase of an architectural project. In this way, promoting students' participation could help achieve a wider consensus regarding a more accessible and adapted design.

To address the process scientifically, a case focused on large-scale urban projects was developed, in particular on the Barcelona Knowledge Campus (BKC), a joint project between the University of Barcelona (UB) and the Polytechnic University of Catalonia (UPC).

Section 2 includes an overview of IT in education and AR technology to view 3D models on-site. It also discusses the use of mobile and geo-learning methods to promote universal access and design for all. The methodology and main features of the experience are described in Sect. 3. Section 4 includes the research results, which are discussed in the final Sect. 5.

## 2 Background

### 2.1 IT in education

The incorporation of IT in today's society has involved new forms of interaction, from communication to entertainment. However, carrying out new learning experiences using IT is not an easy process, and one that is not always successful. In fact, several previous studies have documented the problems and failures in processes of IT implementation in education [6–8]. For these reasons, it is easy to find a wide variety of recent research focused on discovering and implementing "good teaching practices" [9, 10]. Under this category, one may find complex and heterogeneous means (which in many cases are not transferable from one domain to another) of designing content, teaching methodologies, and efficient uses of technological elements [11, 12], in order to achieve successful experiences that improve the curriculum.

To incorporate an IT-based methodology into a specific teaching environment, some recommendations must be considered to avoid student rejection (so-called "good educational practices" that are primarily focused on virtual rooms, e-learning, and semipresent teaching [13, 14]). From these features of specific practices, three points can be extrapolated, as indicated by the following minor objectives:

- Promotion of professor–student relationships, allowing for a more effective feedback process
- Contribution to better task realization by heterogeneous learning methods that meet high expectations
- Applying teaching/learning methods based on teaching innovation and new IT technologies

The authors believe that these new concepts could help to generate a new type of student, much more dynamic and capable of participating more extensively in the educational process (one who could for example be called a "3.0 Student," similar to the evolution of Web 2.0–3.0). At this level, AR or Geo-location technologies, in conjunction with the widespread popularity of mobile devices and their recent advances, open new prospects in mobile learning (ML), a specific field of e-learning (EL) [15].

Due to this approach, it is now possible to design teaching activities in which a student's comments about a particular site are reflected in written form and automatically shared online, becoming part of the new information that other users and students can view and discuss. At this moment, a 3.0 student is situated using the 3.0 Web, a new interactive model of student and education that can generate extra motivation from the students because of the use of their own devices in real environments [16].

### 2.2 3D virtual and geo-located visualization using AR

In architecture and building engineering education, the visual component is one of the most relevant aspects for students, as it is important for students to be able to interpret information visually [5, 17]. 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 digitally presented 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 [18].

The emergence of web-based 3D globe viewers with elevations, satellite and aerial images, maps and 3D features, such as Google Earth© or Virtual Earth©, has promoted the exchange and visualization of geo-referenced 3D models in a natural way. Despite their shortcomings, these visualization tools have achieved greater success than traditional 3D globe viewers based on VRML and X3D [19].

Moreover, the use of an AR urban planning system to allow consultation through mobile devices, as intended in the trial performed in the context of this work has been reported recently [20, 21]. Other authors [22] investigated the use of smartphones as a tool for public participation in urban planning projects, but research addressing these issues is still poorly documented.

Regarding the link between graphical information and its databases updating "on-site," several proposals related to urban and architectural areas can be included, without delving into their educational benefits [23–26]. Furthermore, other proposals discussed the proper integration of spatial data from different sources [27], and most are based on information mapping and use conventional GIS [28]. However, none of these address their use with AR techniques, i.e., superposing the generated model on its planned real site. They are limited to the generation of a virtual model from photographs or laser scanner techniques in order to incorporate these images or geo-referenced 3D models to an associated database.

Finally, it was possible to find a few examples of the use of urban planning systems that use AR to allow consultation through mobile devices, as intended in the exercise presented [20, 22, 29, 30]. Most of these deal with the use of smart phones as a tool for public participation in urban planning projects, though not from an educational standpoint.

To conclude, it can be argued that there is a lack of documented research in educational environments that addresses the problem of urban design by using AR on mobile devices to geo-reference, consult, and evaluate "on-site" architectural proposals. The incorporation of this aspect gives this research an innovative component.

### 2.3 Mobile and geo-learning methods in user engagement to improve design for all and universal access

Currently, one of the most important aspects when conducting any type of project is to make it usable, accessible, and understandable by the greatest possible number of users. In the area of architectural education, this effort should be twofold: on one side, the training method should satisfy these parameters [31], and on the other, students should be aware of them and make universally accessible designs.

Moreover, online education methods have undergone a radical change in the last two decades. They have evolved from closed systems, where the student could only download static content, to new methods that advocate interaction not only between students but also between students and faculty members as well as other users. For these reasons, teachers need to be aware of the students' changing needs.

In order to generate useful recommendations in the Universal Design for Learning (UDL), various projects and discussion forums can be found that have defined the types of educational projects, users, and needs they may have for new teaching methods [32, 33]. According to the following three UDL principles, each area of the curriculum, educational project, or real project should provide multiple, varied, and flexible options for representation, expression, and engagement:

- Provide multiple means of representation
- Provide multiple means of action and expression
- Provide multiple means of engagement.

The experience described in this paper is intended to achieve these goals and create an experience that fits the general parameters of Universal Access [34]: new methods of representation that can more clearly express architectural designs through a more motivating strategy (mobile devices were used because they are usually easily accessible to students, teachers and to the general user)' as well as to clarify the context awareness and content adaptation. In this paper, the context is referred to as contextual information that students can use to evaluate an architectural project using geo-information.

In order to create a useful system adaptable to most users, with or without experience, it is necessary to evaluate the interaction in this new type of mobile learning [35]. For this reason, system usability (AR technology and course opinion) was evaluated. Quality usability indicators were created to control the relationship between the student's learning process and other variables related to the usability of the designed method. Such assessments are not strictly necessary; however, as shown in previous studies [36], they allow to identify both the motivation of the student with the selected technologies and the role of mobile technologies in higher education and professional industry.

Previous studies have discussed the use of 3D visualization in general [37], and specifically AR, for the visualization of architectural designs. This technology helps to adapt them to the environment, avoiding problems of scaling, lighting, and texturing [38–40]. In addition, through these technologies, any user, even outside of the professional sector, can obtain more enjoyable access to virtual information [41].

## 3 Background

### 3.1 Teaching context

The experiment was carried out with students of Architecture and Planning, during the academic year 2011–2012, in an elective course called "ICT applied to Spatial Analysis," which is taught in the Research Master in Land Management and Valuation at UPC, Barcelona-Tech. As mentioned, the researchers worked at BKC (Barcelona Knowledge Campus, see Fig. 1), a project sponsored by the University of Barcelona (UB) and the Polytechnic University of Catalonia (UPC). The project involves academic, research, business, and social entities to provide a framework for strategic collaboration, in order to become a scientific and technological environment of reference in Europe.

Today, the campus includes 227 Ha. Floor area is more than 515,000 sq., and the campus hosts 16 schools, including faculties and colleges, 90 university departments, more than 15 libraries, 2 science and technology parks, and various specialized support centers and management units (Fig. 2). The urban proposal aims to improve the relationship between the campus and the city. It tries to create learning, cultural, social and sporting environments that can improve mobility between the existing parts of the campus.

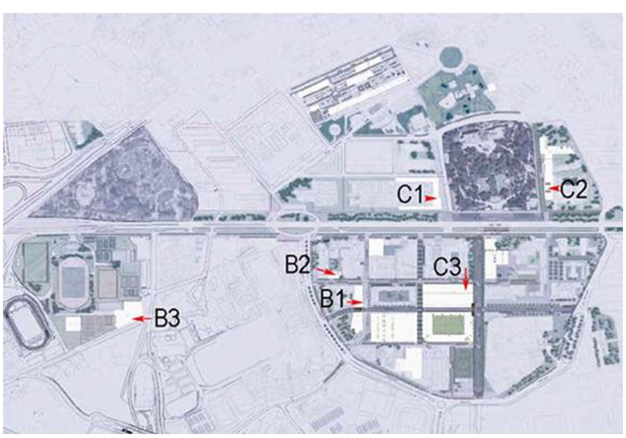


**Fig. 1** BKC. Coding and location of the projects studied

The total duration of the course was 60 h. Currently, this method is being replicated in the 2012–2013 Master's course in Processes and Graphical Expression in Architectural Urban Projection, in the Center of Arts, Architecture and Design (CUAAD, Universidad de Guadalajara, Mexico.

### 3.2 Procedure and geo-location configuration

The first step of the process is based on documents and "planimetric" images provided by the project's managers. Each student had to have a mobile device equipped with a camera, GPS and 3G connection, and was required to download the free browser Layar Viewer©. To visualize the final models, a Geo-location-based AR application that uses GPS, compass, and other sensors in the student's mobile phone was used to provide a "heads-up" display of various geo-located points-of-interest (POI's). In the present case, these were students' architectural proposals situated on the campus.

Students worked with free solutions of SketchUp© and 3dsMax© to create volumetric models and texture designs, using real building materials. They were divided into three different groups, A, B, and C: A for existing buildings, and B and C for new projects named B1, B2, B3, C1, C2, and C3 (Fig. 1).

Each B and C group modeled three proposals with the information provided, exported in *.Obj format (standard format used by AR applications to view 3D models) into the LayerModelConverter© (LMC), which generates a specific file compatible with Layar Viewer. In addition, UTM coordinates should be recorded to be associated with the model in the database. In order to avoid problems, at this point, students should control the export path, check the units, activate the texture maps, and change all YZ coordinates. As a result reference, UTM coordinates and an angle (for example, in the proposed new student dormitory: 41.388010, 2.114627, $\alpha = 40$) are received. These data were introduced into the database joined to the file in *.L3D format.

Previously, an information channel was generated by teachers, as developers, in the Layar public platform. The channel was published using BKC basic information and was configured to allow the use of filters. Comprehensive filters settings helped users to find POIs that were easy and interesting, and to separate proposals by groups (A, B, C). The database and PHP file were hosted in a public server with PHP, MySQL, Java, and support.

As a final step, the students installed the Layar© RA browser on their mobile devices. Once installed, they were required to find the particular channel created, which was located within the category of "geo-layers of architecture and buildings".

**Fig. 2** BKC. Main architectural planned projects

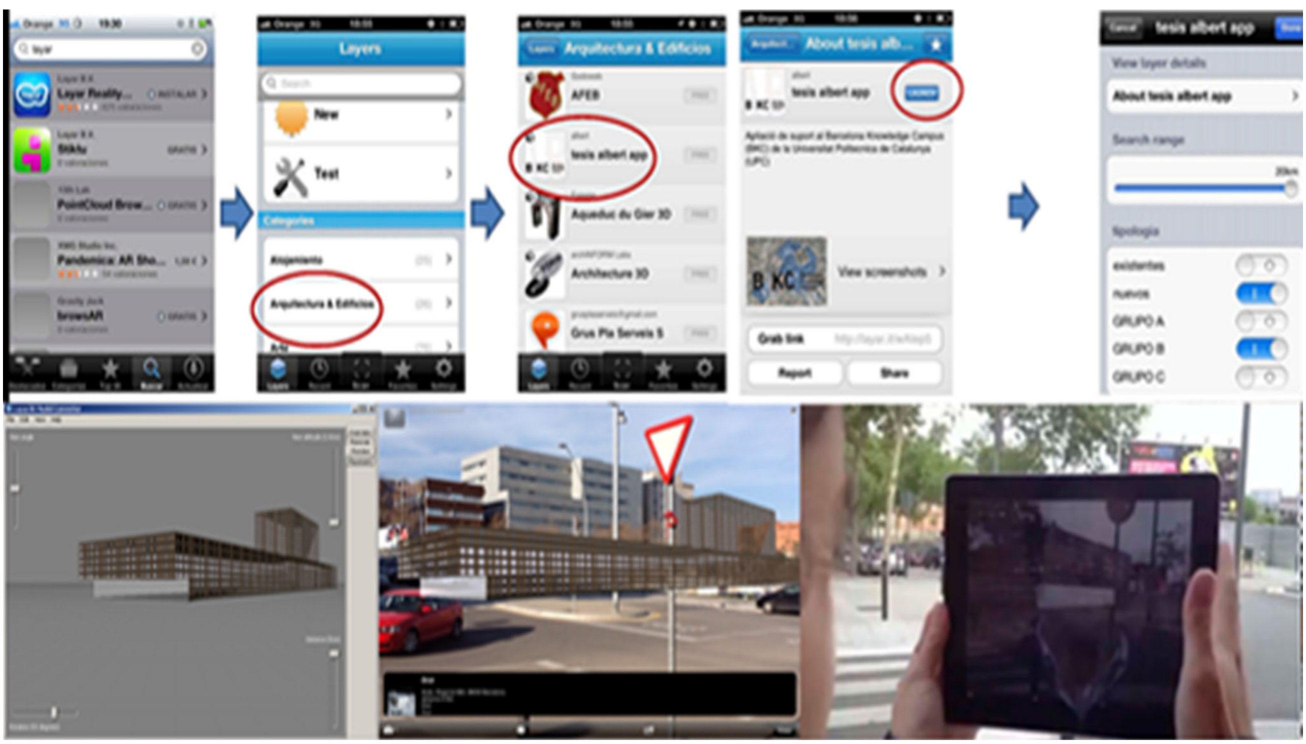


**Fig. 3** Channel configuration example and model visualization "on-site"

Once channel content was downloaded, and every group of students evaluated the models of the other groups "on-site". The queries were sent to the server host, which returned the selected POI. They are shown in the screen superimposed on the real image captured by the camera. As one approaches or focuses on the virtual model, a label at the bottom of the screen appears with the model reference information and distance from the user. By clicking this label, students can access the "iweb" questionnaire where they can respond and make comments about the appearance, impact and the scale of the building (Fig. 3).

### 3.3 Usability parameters definition

Usability is related to the development of interactions with products that are easy to learn, effective, and user friendly. Additionally, usability addresses the subjective perception of whether a system is able to meet all the needs and requirements of users, customers, or managers.

As mentioned, in order to demonstrate the feasibility and effectiveness of this technology in educational settings, on-site questionnaires were designed 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 in respect of the expenditure of time and effort for solving the proposed exercise; and satisfaction, understood as the subjective reactions of users regarding the course.

### 3.4 Test design

During the "on-site" evaluation process, questionnaires associated with own-generated student's geo-referenced 3D models were designed. They were only available when users were close to those virtual models. The basic objective of the questionnaire focused on assessing the degree of adaptation of geo-referenced models in their

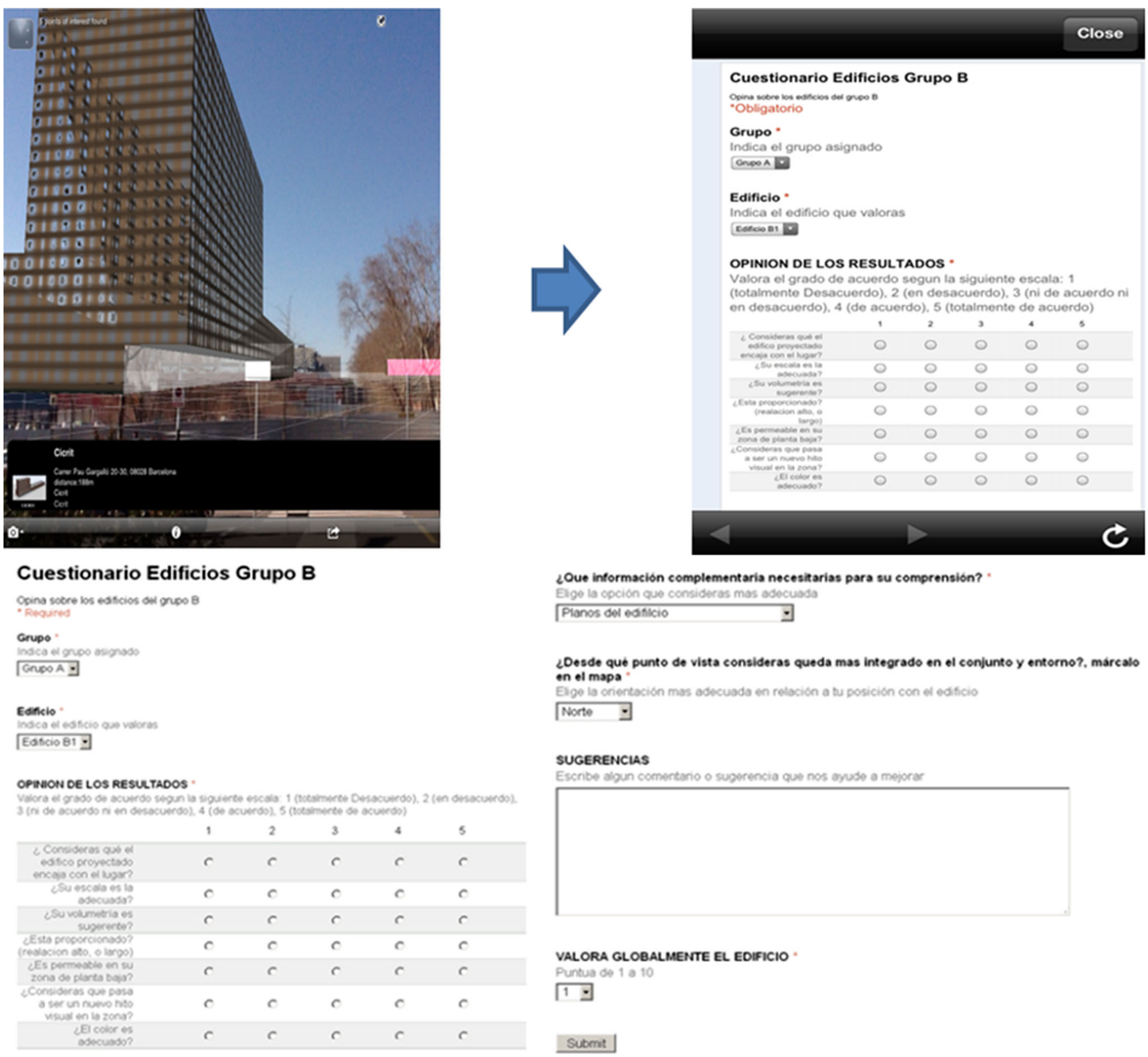


**Fig. 4** Model visualization "on-site" and related questionnaire

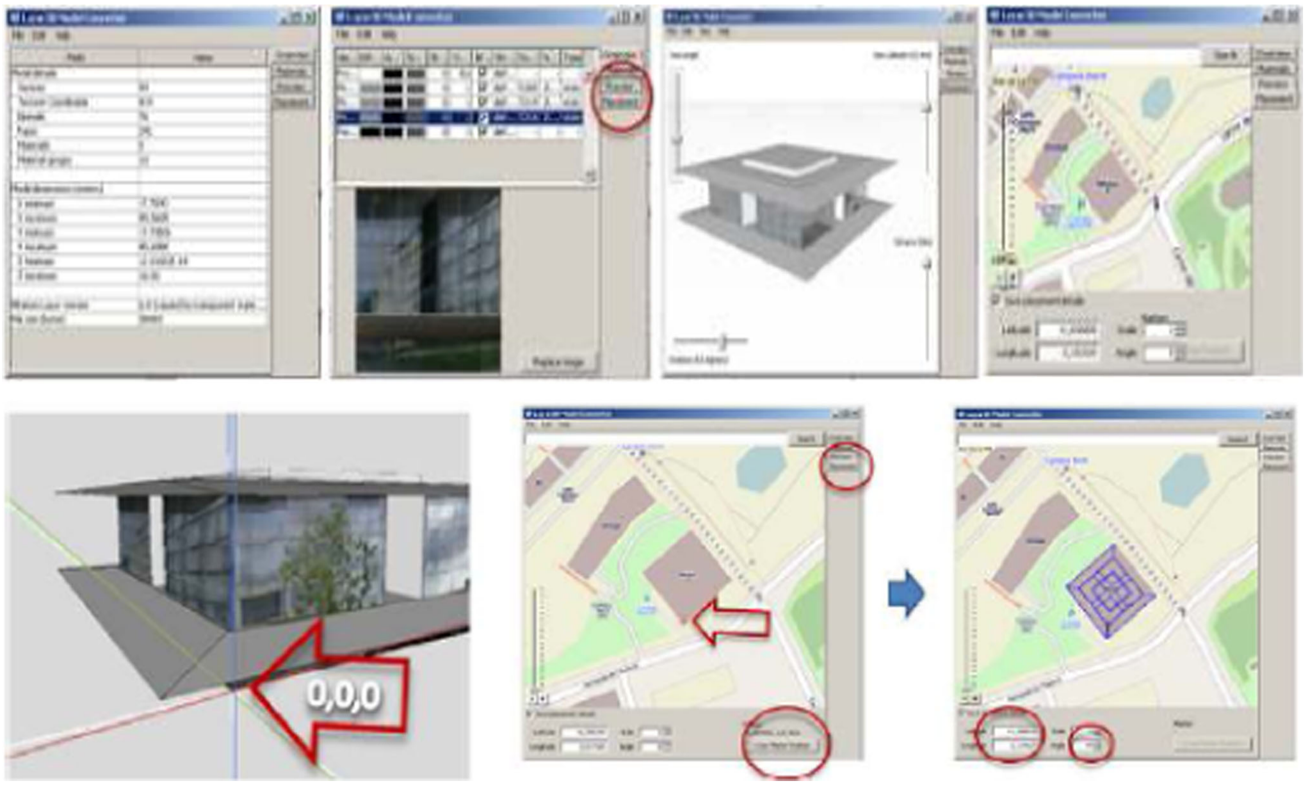


**Fig. 5** Model geo-location using LMC

planned locations, the quality of the models, and items generated by working groups. Furthermore, questions were asked to obtain the students' technological profile and degree of satisfaction (the full sample test can be seen in [42]). Two different questionnaires were designed. In the first, students were asked about the use of AR technology and system usability assessment in the case of existing buildings, according to a standardized methodology for these experiments.

In the second, students evaluated and reviewed all information linked to new buildings (Fig. 1), as project plans, memory, or project rendered views, which provided additional insights. In addition, students were required to choose the best viewpoint from which to appreciate the integration of the new project with the existing building (Fig. 4).

In both cases, personal responses were sent directly to the teacher who received and analyzed the information.

### 3.5 Model generation of the case of study

As already mentioned, one of the objectives of this type of experience is to familiarize students with the use of new tools for architectural representation using their environment and known nearby devices.

With previous knowledge of CAD/BIM (Computer Assisted Design/Building Information Modeling) and thanks to the information provided on the site (planning regulations, etc.), students were expected to be able to complete the steps described in Sect. 3.2. Lighting simulation, mapping, and texturing techniques were used to give 3D models a realistic look. Once the models were exported to *.obj format, position information in real coordinates (Fig. 5) through the LayarModelConverter (LMC) application was to be obtained.

## 4 Results

The course was completed (100 % of proposed tasks) by a total of 11 students. In total, six campus buildings were modeled (see Fig. 6).

As expected, students were able to follow all steps described in the previous sections to visualize their proposals on the intended location using their devices. While model registration using GPS was inaccurate, as expected, the use of semitransparent texture mapping, and model visualization at a distance, allowed for a scene generation accurate enough to represent the proposals and allow their urban impact evaluation "on-site."

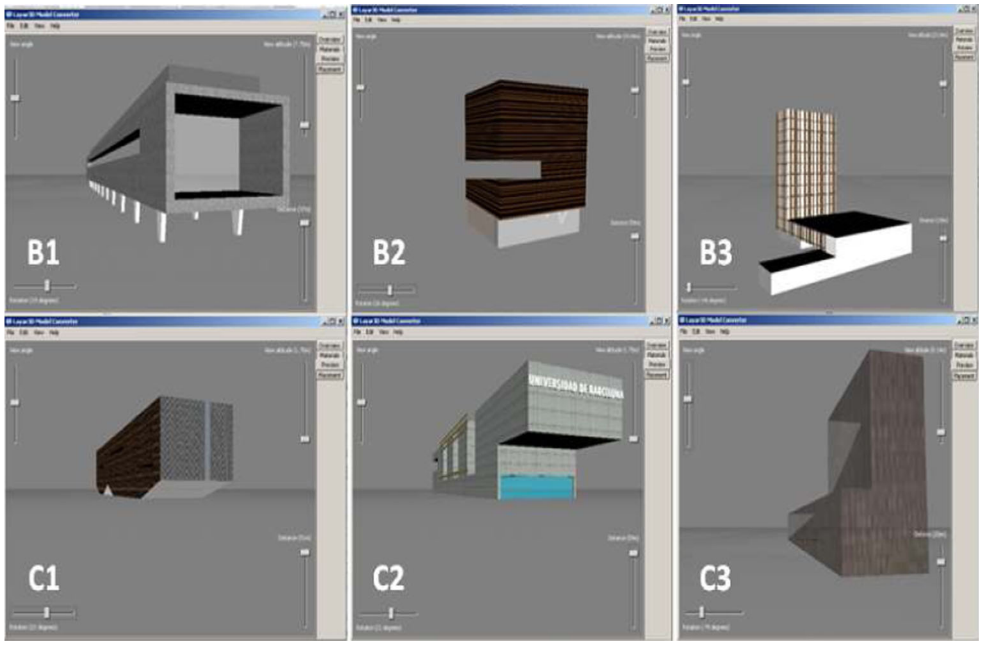


Fig. 6 Results of the architectural proposals modeled by students in L3d format to be uploaded to the database

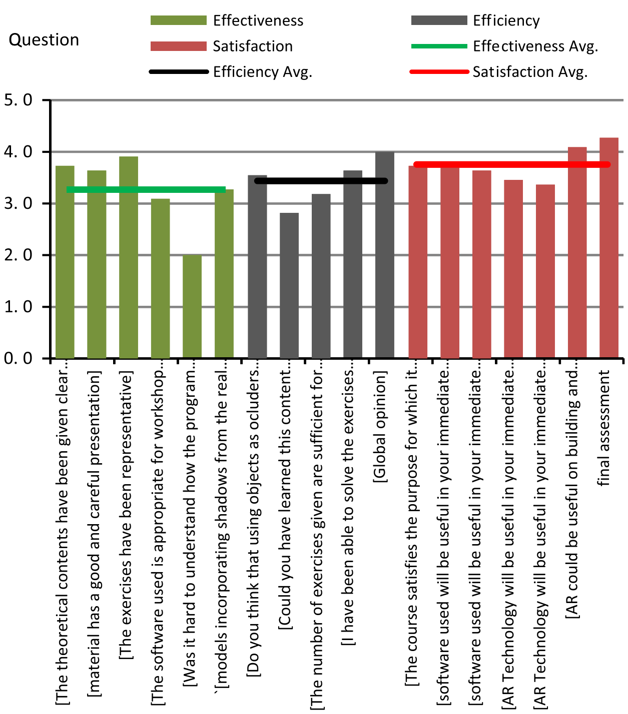


Fig. 7 Student responses to questionnaire grouped by usability guidelines

### 4.1 Main results of the BKC study case

The average scores of the responses, related to the main usability guidelines (effectiveness, efficiency and satisfaction), were very similar, ranging from 3.31 to 3.46 out of 5 (Fig. 7).

The overall assessment was rated at 4.27 points out of 5, which confirms the feasibility of using this technology in educational environments. Effectiveness average was 3.27 out of 5, and Efficiency and Satisfaction were 3.44 and 3.75 respectively.

However, independently, the response interpretation is complex. To provide a clearer interpretation and allow the information to be presented in a brief and concise manner, there is a need to group these responses. Consequently, it is necessary to construct composite indicators, which in the present case were: knowledge level, previous training, effectiveness, efficiency, and satisfaction.

These indicators do not provide a full explanation of the latent variable (usability), but allow to obtain "quality" indicators from each student. They cannot be measured in units, but allow comparisons between students of different courses and to form correlations with other indicators, such as academic performance. In addition, they represent a useful approach to usability study and help draw conclusions objectively.

For this Principal Component Analysis (PCA) through SPSS, V11 software was used. Once major components and contribution rates were estimated, each of the students was assessed according to an index derived from a general expression that weights the scores for each principal component to the square root of the variance [43] as follows (expression to construct usability's compound indicators):

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

where $I_{mj}$ represents the composite indicator to be achieved (efficiency, satisfaction, effectiveness, etc.) for each $j$-th

**Table 1** Five students sample table correlating questionnaire responses with usability ratings

| Questions | Variables\students | 2 | 5 | 8 | 7 | 1 |
|---|---|---|---|---|---|---|
| [The theoretical contents have been given clear and representative] | W_contents | 5 | 2 | 2 | 5 | 3 |
| [Material has a good and careful presentation] | W_material | 4 | 2 | 2 | 5 | 4 |
| [The exercises have been representative] | W_exercises | 5 | 1 | 2 | 5 | 5 |
| [The software used is appropriate for workshop objectives] | W_software | 5 | 2 | 3 | 5 | 5 |
| [The course satisfies the purpose for which it was designed (New Graphical tools or presentations)] | W_crs_prp | 5 | 2 | 3 | 5 | 5 |
| [Could you have learned this content independently?] | W_learn_ind | 3 | 3 | 3 | 4 | 5 |
| [The number of exercises given are sufficient for hours of proposed work] | W_num_ex | 4 | 2 | 3 | 4 | 5 |
| [I have been able to solve the exercises presented] | W_solve | 5 | 3 | 3 | 4 | 5 |
| [Workshop Global opinion] | W_G_op | 5 | 2 | 1 | 5 | 5 |
| [Was it hard to understand how the program works?] | T_hard_prog | 1 | 2 | 1 | 3 | 1 |
| [Software used will be useful in your immediate future as a student?] | T_soft_stu | 5 | 2 | 2 | 5 | 5 |
| [Software used will be useful in your immediate future as an engineer?] | T_soft_eng | 5 | 3 | 3 | 5 | 5 |
| [AR Technology will be useful in your immediate future as a student?] | T_AR__stu | 5 | 2 | 1 | 5 | 3 |
| [AR Technology will be useful in your immediate future as an engineer?] | T_AR_eng | 5 | 3 | 2 | 5 | 3 |
| [AR could be useful on building and architectural areas?] | T_AR__areas | 5 | 2 | 2 | 5 | 4 |
| [Models incorporating shadows from the real environment is important to make the scene more realistic?] | T_shadows | 5 | 2 | 2 | 3 | 5 |
| [Do you think that using objects as occluders help integrate the model in the scene?] | T_occluders | 5 | 2 | 2 | 3 | 4 |
| Final assessment | F_assessment | 5 | 2 | 2 | 5 | 4 |
| Q. 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 index | | 1.00 | 0.00 | 0.09 | 0.82 | 0.93 |

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 1 shows the results obtained from five students, comparing questionnaire response averages with the usability index and each component.

Table 1 shows that Student 2 obtained the highest usability and highest average scores in his responses. Student 5, in contrast, had the worst average scores 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. These findings confirm the consistency of the indicator construction.

Finally, to identify the most significant variables related to the overall course opinion, the students' final assessment was correlated with main variables (Table 2).

High correlations were detected correlating the representativeness of the exercise (W_exercises = 0.92) and material presentation (W_material = 0.80). 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 = 0.34) or previous knowledge of AR technology (AR_App = −0.11) did not correlate significantly with the students' global opinion of the course.

**Table 2** Correlations between the students' final assessment and other variables

| | AR_App | W_contents | W_material | W_exercises | W_software | W_course_purpose | W_learn_indep | W_num_exercises | W_solve |
|---|---|---|---|---|---|---|---|---|---|
| P.Corr | −0.11 | 0.66 | **0.80** | **0.92** | 0.53 | **0.82** | 0.34 | 0.24 | 0.64 |
| N | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |

Bold values indicate high Pearson correlation (>0.75)

## 5 Results

As can be seen, the variable *prior knowledge of augmented reality applications* (Ar_app) and the variable indicating *the fact of being able to learn these contents without teacher* (W_learn_indep) are not correlated at all (0.34), or even in a slightly negative way (−0,11), with the students' final assessment of the course. There is also a slight positive correlation (0.24) in the variable concerning the *number of exercises in relation to the hours of dedication* (W_num_exercises). It is evident that an overload of work affects the students' opinion of the course negatively. The low correlation, however, indicates that this fact is not greatly relevant.

Significant correlations were detected (close to 0.70) with the variables that address the *purpose, material, content and software used*. These four variables appear to affect the opinion of enrolled students similarly. Finally, the highest correlation (0.92) is for the question of the *representativeness of the proposed exercise* (W_exercises). It seems that the choice of exercise, and its suitability in relation to the content taught, greatly influences the students' global opinion.

Related to usability indicator construction, there is a direct relationship between the "response" means and the usability index assigned to each student. However, the methodology used ensures that the components with higher explained variance have a greater weight in the index construction, so it can be used to correlate with other indicators, such as academic performance. In addition, the consistency of the indicator construction represents a useful approach to study usability and helps draw conclusions objectively.

## 6 Conclusions

In relation to the technology used, responses confirm that performance improvement of mobile (handheld) devices has made them useful tools for using AR technology in the field of architecture and building. The features of these devices have traditionally been inadequate in this area, where greater computational capabilities are needed (complex and accurate models rendering, or several options and scenes simultaneous analysis). Students felt that this technology could be useful for both their training and their future as professionals.

In relation to usability, results obtained from effectiveness, efficiency, and satisfaction indicators show that the low degree of immersion provided by these devices (monitor–based), as well as limited interaction with the small size of their screens, seems to be enough to guarantee the feasibility of these kinds of experiences.

Furthermore, the methodology used, based on a low-cost system that performs a study case, can be extrapolated to other research areas. However, in order to provide universal access to these new technologies in educational environments, a usability analysis should always be incorporated. It would help to ensure acceptable levels of availability, affordability, and satisfaction of the technology used. In addition, some points should be considered:

- Most of the students do not have previous knowledge of software used—in this case, GIS systems, modeling programs, and CAD applications. They should learn it during the course, and most of the time they do not feel able to learn the content autonomously (without an instructor). These constrains, however, do not clearly correlate with the final assessment of the course.
- Exercise representativeness is crucial for the success of this type of experience. This key variable obtained the best score and had the highest correlation with the positive assessment of the course.
- Credible integration of the model in the scene (through immersion light and the use of occluded techniques) is the best qualified variable, so it should be considered essential in later AR courses.

Finally, some difficulty in learning and an excessive number of exercises in relation to scheduled work hours was found. This fact does not preclude the overall positive evaluation of the experience, though it must be taken into account to ensure a successful experience. For future work, correlations between usability indicators and students' academic performance must be carried out.

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## References


1. Redondo, E., Sánchez, A., Perede, A., Fonseca, D.: Geo-Elearning. Geolocated Teaching in urban environments through mobile devices. A case study and work in process. In: Schumaker R. (ed.) Virtual, Augmented and Mixed Reality. Systems and Applications, AMR/HCII 2013, Part II, Lecture Notes in Computer Science—LNCS 8022, pp. 188–197. Springer, Heidelberg (2013)
2. Roca, J., Gagné, M.: Understanding e-learning continuance intention in the workplace. A self-determination theory perspective. Comput. Hum. Behav. **24**, 1585–1604 (2008). doi:10.1016/j.chb.2007.06.001
3. Kreijns, K., Acker, F.V., Vermeulen, M., Buuren, H.V.: What stimulates teachers to integrate ICT in their pedagogical practices? The use of digital learning materials in education. Comput. Hum. Behav. **29**, 217–225 (2013). doi:10.1016/j.chb.2012.08.008
4. Shen, C.X., Liu, R.D., Wang, D.: Why are children attracted to the Internet? The role of need satisfaction perceived online and perceived in daily real life. Comput. Hum. Behav. **29**(1), 185–192 (2013). doi:10.1016/j.chb.2012.08.004
5. Fonseca, D., Martí, N., Redondo, E., Navarro, I., Sánchez, A.: Relationship between student profile, tool use, participation, and academic performance with the use of Augmented Reality technology for visualized architecture models. Comput. Hum. Behav. (2013). doi:10.1016/j.chb.2013.03.006
6. Milliken, J., Philip-Barnes, L.: Teaching & technology in higher education: Student perceptions and personal reflections. J. Comput. Educ. **39**(3), 223–235 (2002)
7. Georgina, D.A., Olson, M.R.: Integration of technology in higher education: A review of faculty self-perceptions. Internet High. Educ. **11**, 1–8 (2007)
8. Redacción de Educaweb: El 52 % de los docentes ha tenido problemas para utilizar las TIC en el aula debido a fallos técnicos. Retrieved March 18, 2013. www.Scolartic.com published January (2013)
9. Valverde, J., Garrido, M.C., Fernández, R.: Enseñar y aprender con tecnologías: un modelo teórico para las buenas prácticas con TIC. Revista de Teoría de la Educación Sociedad de la Información, (TESI) **11**(3), 203–229 (2010)
10. State Education Resource Center (SERC): Best Practices from the State Education Resource Center. Retrieved April 4, 2013. http://ctserc.org/docs/SERCWorks-spring2011.pdf (2011)
11. Rogers, D.L.: A paradigm shift: technology integration for higher education in the new millennium. Educ. Technol. Rev. **13**, 19–27 (2000)
12. Bates, A.W., Pole, G.: Effective teaching with technology in higher education: Foundations for success. Jossey-Bass Inc., U.S. (2003)
13. Área, M.A., San-Nicolás, M.B., Fariña, E.: Buenas prácticas de aulas virtuales en la docencia universitaria semipresencial. Revista de Teoría de la Educación Sociedad de la Información **11**(3), 7–31 (2010)
14. Salinas, J.: Innovación docente y uso de las TIC en la enseñanza universitaria. Revista de Universidad y Sociedad del Conocimiento (RUSC) **1**(1), 1–16 (2004)
15. Georgiev, T., Georgieva, E., Smrikarov, A.: M-learning—a new stage of E-learning. In: International Conference on Computer Systems and Technologies, CompSysTech. (2004)
16. Sharples, M.: The design of personal mobile technologies for lifelong learning. Comput. Educ. **34**, 177–193 (2000)
17. Boeykens, S., Santana-Quintero, M., Neuckermans, H.: Improving architectural design analysis using 3D modeling and visualization techniques. In: Ioannides, M., Addison, A., Georgopoulos, A., Kalisperis, L. (eds.) Digital Heritage: 14th International Conference on Virtual Systems and Multimedia Pages, pp. 67–73. Limassol, Cyprus (2008)
18. Bouchlaghem, D., Shang, H., Whyte, J., Ganah, A.: Visualization in architecture, engineering and construction (AEC). Int. J. Autom. Constr. **14**, 287–295 (2005)
19. Breunig, M., Zlatanova, S.: 3D geo-database research: retrospective and future directions. Comput. Geosci. **37**(7), 791–803 (2011)
20. Anagnostou, K., Vlamos, P.: Square AR: using augmented reality for urban planning. 2011 Third International Conference on Games and Virtual Worlds for Serious Applications, IEEE, pp. 128–131 (2011)
21. Lonsing, W.: Architectural models in urban landscapes: synthesis of markers and virtual structures. IEEE International Symposium on Mixed and Augmented Reality—Arts, Media, and Humanities, IEEE, pp. 109–110 (2011)
22. Allen, M., Regenbrecht, H., Abbott, M.: Smartphone augmented reality for public participation in urban planning. In: Proceedings of the 23rd Australian Computer–Human Interaction Conference on—OzCHI'11, pp. 11–20. ACM Press, New York, USA (2011)
23. Huang, B., Jiang, B., Li, H.: An integration of GIS, virtual reality and the Internet for visualization, analysis and exploration of spatial data. Int. J. Geogr. Inf. Sci. **15**(5), 439–456 (2001)
24. Kwan, M.P.: Interactive geovisualization of activity-travel patterns using three-dimensional geographical information systems: a methodological exploration with a large data set. Trans. Res. Part C Emerg. Technol. **8**(1–6), 185–203 (2000)
25. Hernández, J., García, L., Ayuga, F.: Assessment of the visual impact made on the landscape by new buildings: a methodology for site selection. Landsc. Urban Plann. **68**(1), 15–28 (2004)
26. Droj, G.: Cultural heritage conservation by GIS, Nyugat-Magyarországi Egyetem, Geoinformatikai Kar, Székesfehérvár, University of Oradea, pp. 1–10 (2010)
27. Belussi, A., Migliorini, S.: A framework for integrating multi-accuracy spatial data in geographical applications. GeoInformatica **16**(3), 523–561 (2011)
28. Hosse, K., Schilcher, M.: Temporal GIS for analysis and visualization of cultural heritage. In: Proceedings of CIPA XIX International Symposium, Commission V, WG5, pp. 1–6. Antalya, Munich (2003)
29. Ismail, A. W., Sunar, M. S.: Multi-user interaction in collaborative augmented reality for urban simulation. Second International Conference on Machine Vision, IEEE, pp. 309–314 (2009)
30. Lonsing, W.: Architectural models in urban landscapes: synthesis of markers and virtual structures. IEEE International Symposium on Mixed and Augmented Reality, pp. 109–110 (2011)
31. Craft, Brock, Mor, Yishay: Learning design: reflections on a snapshot of the current landscape. Res. Learn. Technol. **20** (2012). doi:10.3402/rlt.v20i0.19196
32. Kelly, P.; Universal design for learning: meeting the needs of all students. THE ASHA LEADER. ASHA.org, August 30, 2011. Retrieved: October 3 (2013)
33. Mor, Y.: Designed for learning, August 6, 2012 Retrieved: October, 3. http://designedforlearning.wordpress.com/ (2013)
34. Yang, S.J.H., Chen, I.Y.L.: Universal access and content adaptation in mobile learning. Advanced Learning Technologies, 6th International Conference, pp. 1172–1173. doi:10.1109/ICALT.2006.1652678 (2006)
35. Kondratova, I.: Multimodal interaction for mobile learning. Universal access in human–computer interaction. Intelligent and ubiquitous interaction. Environments **5615**, 327–334 (2009). doi:10.1007/978-3-642-0271-9_36
36. Motiwalla, L.: Mobile learning: a framework and evaluation. Comput. Educ. **49**, 581–596 (2005). doi:10.1016/j.compedu.2005.10.011

37. Pittarello, F.: Accessing information through multimodal 3D environments: towards universal access. Univ. Access Inf. Soc. **2**(2), 189–204 (2003)
38. Wang, X., Dunston, P.S.: Compatibility issues in augmented reality systems for AEC: an experimental prototype study. Autom. Constr. **15**(3), 314–326 (2006)
39. Irizarry, J., Gheisari, M., Williams, G., Walker, B.N.: InfoSPOT: a mobile augmented reality method for accessing building information through a situation awareness approach. Autom. Constr. **33**, 11–23 (2013)
40. Hammad, A., Wang, H., Mudur, S.P.: Distributed augmented reality for visualizing collaborative construction tasks. J. Comput. Civil Eng. **23**(6), 418–427 (2009)
41. Fonseca, D., Puig, J.: QR-codes applied to architecture data and teaching. In: Proceedings of 5th International Multi-Conference on Society, Cybernetics and Informatics, Vol. 2, pp. 232–236 (2011)
42. Redondo, E., Sánchez, A., Fonseca, D., Navarro, I.: Geo-elearning for urban projects. New educational strategies using mobile devices. A case study of educational research. Architecture, City, and Environment. Accepted 8 October (2013)
43. Peters, W.S., Butler, J.Q.: The construction of regional economic indicators by principal components. Ann. Reg. Sci. **4**(1), 1–14 (1970). doi:10.1007/BF01287726