AN EDUCATIONAL APPLICATION BASED ON VIRTUAL REALITY TECHNOLOGY FOR LEARNING ARCHITECTURAL DETAILS: CHALLENGES AND BENEFITS

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Abstract

Architectural learning is intensely multifaceted and faces many challenges. Educational theories such as Problem Based Learning, Flipped Learning, Learning Styles theory, and Experiential Learning theory are researchers’ responses to those challenges. In fact, many of these theories need proper means in order to be effectively applied in architectural education. Moreover, the possibilities provided by Virtual Reality (VR) Technology, combined with the complex intrinsic properties of architectural pedagogy, place this technology under architecture researchers’ constant watch. With its experiential nature, VR technology can improve architectural students’ learning. Although the study of VR applications for educational purposes is not new, this is rarely studied in the light of emerging learning theories in architectural education. In response, an educational application called LADUVR (“Learning Architectural Details Using Virtual Reality Technology”) has been designed by the authors to show how VR would address the current shortcomings of architecture learning systems. The present paper discusses the benefits and challenges of developing these kinds of applications, and shows how by using LADUVR users can experience being on a construction site, investigate the architectural details closely, and test what they have learned in an interactive and immersive environment. To continue, the paper examines the feedback from the implementation of LADUVR; with the results indicating that LADUVR would indeed enhance the learning of architectural detailing in most aspects. The paper concludes with a comparison between the use of this application and conventional learning methods.
INTRODUCTION

Even though humankind has been familiar with the concept of Virtual Reality since the 1930s (as introduced in Stanley G. Weinbaum’s 1935 book Pygmalion’s Spectacles), the concept has faced challenges to realize. CAVEs (Cave Automatic Virtual Environment) and HMDs (Head-mounted Display) like the “Sword of Damocles”, “Sensorama”, “Sega VR”, etc. are technologies that have been developed since that time to realize immersive virtual environments. The decrease in the cost of providing tools for experiencing virtual environments in an immersive and interactive fashion, in addition to the tremendous amount of software and other hardware development in the recent years, leads to the availability of VR for public users. At present, HMDs are the most convenient tools for delivering a virtual reality experience with a high degree of immersion.

Nowadays, investment in the VR market is raising expeditiously. It is anticipated that the total revenue of VR and Augmented Reality (AR) market would reach $120 billion in 2020 (Augmented/Virtual Reality Report, 2016). On the other hand, the e-learning market has an intense influence on the education market. A report expects the growth of e-learning market from $165.21 billion in 2015 to $275 billion in 2022 (Costello, 2017). Undoubtedly, the emergence of virtual reality would be a substantial contributor to the flourishing market of e-learning.

Alongside investments in this area, the increase in research on the applications of VR is remarkable. If we search the word “Virtual Reality” in the Science-Direct database (https://www.sciencedirect.com), the growth in the number of articles about VR from 1087 in 1999 to 4800 in 2016, claims that the virtual reality phenomenon is an increasingly interesting topic for researchers. The above data indicates the crucial role of VR in the future human transactions. Confirming this, Michael Heim (1994) describes VR as ‘a technology that can be applied to every human activity and can be used to mediate in every human transaction’. One of the many possible implications of this revolutionary technology would be developing educational applications especially for architectural purposes.

Many educational theories and models introduced by pioneers in the field acknowledge flaws in traditional learning and teaching. For example, educational theorists such as David A. Kolb (1976), Richard M. Felder (1988), Isabel Briggs Myers (1985), and Fleming & Mills (1992) believe that learners’ preferences differ from each other. Architecture pedagogy faces such challenges no less than other disciplines (Banerjee, 1996; Nabih, 2010; Danaci, 2015). For instance, a challenge more specifically confronted by architecture students is how to convert the knowledge into practice (Banerjee, 1996).

In response to architectural education’s challenges, LADUVR (“Learning Architectural Details Using Virtual Reality Technology”) is designed to take advantage of potential benefits of VR technology. With its immersive virtual environment and interactive interface, LADUVR is designed to help architecture students with learning contents of architectural detailing in their curriculum. LADUVR’s approach to learning is in harmony with problem based learning, experiential learning and flipped learning theories.

RESEARCH QUESTION AND METHODOLOGY

The main questions addressed in this paper are ‘how virtual reality technology fills the gaps in architectural pedagogy?’ and ‘what are the characteristics of a virtual reality educational
application in this field regarding emerging theories in architectural education?’ To answer, a design science research (Creswell, 2009; Peffers et al., 2007) approach is adopted. The objective of this approach is to design, develop and evaluate an educational application based on virtual reality technology for learning architectural details regarding new theories in architectural pedagogy.

Figure 1. Research process of this article (Source: Authors).

Starting with a review of some well-known challenges of architectural education and emerging learning theories that argue challenges in current architectural pedagogy, the paper then moves on to clarify the importance of the problem by conducting a survey among architectural students. This paper discusses virtual reality technology as an established tool for educational purposes. Moreover, this paper seeks to extract characteristics of an effective educational application based on virtual reality for a theoretical course in architecture (architectural detailing aka construction). A report on these stages of the research is then followed by the introduction of an educational application designed and developed by the authors based on VR technology named LADUVR. Finally, the implementation of LADUVR is scrutinized. In order to understand the effectiveness of this application, semi-structured interviews were conducted among eight students who have taken construction detailing courses within the last year.

LITERATURE REVIEW

Architectural Education Challenges

Architectural learning is intensely multifaceted and challenging (Banerjee, 1996). Students need to deal with structural questions on one hand, review historical periods of ancient cities for history courses on the other, and also involve design studios and their complicated image production challenges. Such challenges in teaching architecture and related disciplines have been observed by the likes of Vincent Canizaro (2012) and Greig Crysler (2013).

In addition to all these difficulties in architectural pedagogy, incompetency in transferring knowledge into practice is one of the major issues (Banerjee, 1996; Nabih, 2010). Hacer Danaci (2015) suggests that the final purpose of architectural education is to make students...
capable of implementing theories into the design and also mentions that the knowledge that comes from memorizing will be forgotten soon and even repetition of that process would not help.

Architecture comprises diverse and sometimes disjointed, discipline areas within a unified framework (Nabih, 2010) and it makes architectural education an immense challenge. Some architects split architecture education into two areas: primary architectural lessons like learning to design; and para-architecture lessons namely structural and mechanical courses (Nadimi, 2017). Some others categorize architectural courses into three sub-categories of knowledge, skill, and design. The extent of architectural related fields in addition to the increasing pace of science development affirm that catching up with the latest knowledge in architecture is certainly a challenge for students, however, Ujwala Chakradeo (2010) believes that new technologies will evolve the learning of knowledge and skills in the near future and students and instructors can easily use them worldwide. Although new technologies can be beneficial in every aspect of architectural pedagogy, and that these technologies can offer effective ways of learning, the focus of this article is just on knowledge-based courses in the curriculum.

Moreover, theories about learning in architecture have been discussed in many studies to address the challenges mentioned before. The explanation of some of these theories and their relation with virtual reality technology is discussed in the following sections. There is an anticipation by the authors that with the help of principles and features mentioned in those theories, we could create an effective VR application for architectural education.

It is noteworthy to mention that there are other learning theories in architectural education that can utilize new technologies and enhance learning, which is beyond the scope of this paper. For instance, the SOLE model developed by Mohd Zairul (2018) that is a student-centered learning (SCL, aka Self-Directed Learning introduced by Knowles (1975)), theory inspired by self-determination theory of Deci & Ryan (2008) and the Rich Environments for Active Learning (REAL) model (Grabinger & Dunlap, 1995). These theories need interactive, student-centered learning environments which rely on intentional learning.

**Problem Based Learning**

One of the emerging theories in architectural pedagogy is Problem Based Learning (PBL). PBL is an innovative educational theory that was introduced at McMaster University in Canada at the end of the 1960s (Camp, 1966). Many studies have been done on the implementation of PBL in architectural courses (Bridges, 2007). With the PBL method, the learning process is initiated by a problem and students identify the information required to solve the problem (Bibbings, Bieluga & Mills, 2018). Being problem based rather than subject based means that students critically question and draw their own conclusions about what they have experienced. Alongside that, the student’s learning is not fragmented into different specialties or teaching sessions. They reflect upon prior learning, analyses and synthesize the contextual information, acquire further knowledge and assimilate into their existing knowledge base (Wong & Lam, 2007).

**Flipped Learning**

Despite the benefits of e-learning and remote education, researchers claim that fully online learning is not what students are seeking. Instead, learners prefer a blended learning
approach (Rovai & Jordan, 2004; Garrison & Vaughan, 2011; Allen & Seaman, 2013). The flipped classroom is based on a blended learning approach, which means “there is an integration of both face-to-face and remote delivery methods” (Partridge et al., 2011). The flipped classroom is not a new topic in educational research studies, however, this concept has become popular due to the recent advancement and availability of technology (Davies et al., 2013).

Experiential Learning

Pioneer theorists of education emphasize a kind of teaching that comes from experience. Kolb (1984) posits that learning is a process that involves making knowledge through a transformation of experiences. This approach conforms to the theory of Constructivism: a theory of gaining information, which suggests humans obtain knowledge by learning from their experiences. Experiential learning has long been a part of architecture and engineering education (Harrisberger, 1976). For instance, Kerry Mulligan et al. (2018) discuss how experiencing a situation could affect the way we think about an architectural problem and suggest that experiential learning should be embedded in architectural education.

HAASE (as cited in Salama, 2006) argues that by incorporating experiential learning theory in architectural education it is possible to fill the gaps between education and the act of building. Also, it would better equip students to critically understand and overcome challenges they might face in their future. Salama also emphasizes on the importance of experiential learning in architectural education by stating that although there is a tremendous diversity of approaches and methods in architectural education, experiential learning seems to be a common key issue discussed in the studies about architectural education. He pushes forth the idea by mentioning that education theorists including Benjamin Bloom, David Kolb, Jean Piaget, John Dewey, and Paulo Freire believe that experiential learning should be an integral part of any pedagogical system.

Learning Styles

Students learn in different ways. Richard M. Felder (1988), one of the theorists of education, discusses these differences in his paper about education in engineering classrooms. He suggests that some people prefer to acquire knowledge visually, however many others are inclined to auditory sources of knowledge. Some people learn better by doing, while some others are more efficient by contemplating a problem. He also states that not only learners are different from each other, but also the methods of teaching are diverse.

Educational models classify learners into various types regarding their learning preferences. Felder (1988), Kolb (1976), Fleming (1992), and other researchers have grouped learners according to their characteristics in separate categories and suggested corresponding learning styles. Importantly, as soon as teachers understand these differences they might find themselves obliged to devise different teaching methods for every learning style. Felder (1988) states that ‘how much a given student learns in a class is governed in part by that student’s native ability and prior preparation but also by the compatibility of his or her learning style and the instructor’s teaching style’. His study strongly suggests that existing mismatches between teaching and learning in the present engineering education reduce educational efficiency.
Felder divides learners into five major groups: 1. Sensing and Intuitive Learners, 2. Visual and Auditory Learners 3. Inductive and Deductive Learners 4. Active and Reflective Learners, 5. Sequential and Global Learners. Although this categorization has similarities with those of Jung (1971) and Kolb (1984), the concentration of Felder’s studies on engineering education makes it appropriate for further research in architectural education. The following list of the characteristics of learners provides guidelines as to how an educational approach should provide assistance particularly for the hitherto neglected types:

**Sensing and Intuitive Learners**

According to Jung (1971 as cited in Felder, 1988), people would prefer to understand their surrounding area in two different ways; some people are inclined to contemplate and speculate about their environments, others are more comfortable to utilize their senses to understand their world. Felder also states that a considerable proportion of engineering students are sensory learners and that is in contrast with the fact that most engineering courses except for laboratories emphasize on principles and theories.

**Visual and Auditory Learners**

According to Felder (1988), humans differ not only in how they understand their surrounding world but also in the ways they obtain information. Visual, Auditory and Kinesthetic are the three styles he introduces in his model, but he intentionally ignores the third category. A possible explanation for this decision is that he was unable to find a feasible solution to convey kinesthetic information. However, in the present time, new technologies have solved this problem at least in the laboratory. Researchers have developed technologies to transfer and simulate the senses of smelling and touching that could be used in the near future for presenting kinesthetic data in classrooms. These new technologies are part of VR’s hardware to enhance the immersion degree. Richardson (1984 as cited in Felder, 1988) argues that majority of college students are visual learners while most college teaching styles are auditory or a visual representation of auditory data.

**Inductive and Deductive Learners**

Philosophers divide reasoning into two groups: Inductive and Deductive reasoning. In Inductive reasoning, humans use evidence and observations to build principles and general rules. Through Deductive reasoning on the other hand, individuals are able to explain a phenomenon by using principles. Samir Okasha (2002) argues that although the Deductive reasoning is more trustworthy than Inductive reasoning, humans use the latter constantly in their lives.

Felder also believes people are Inductive or Deductive learners based on their learning preferences. At least half of the teachers in engineering classrooms are Deductive teachers. Having said that, Hilda Taba (1966 as cited in Felder, 1988) and McConnell (1934 as cited in Felder, 1988) argue that inductive teaching approach improves learning and would bring in academic achievement.
Active and Reflective Learners

Felder (1988) classifies learners into two types based on how they transfer obtained information to the knowledge: Active and Reflective learners. He puts forth the theory by stating that, Reflective learners are in fact introspective people, however, Active learners prefer to do active experiments. It seems that there are some similarities between experiential learning’s principles, PBL and Active learners’ characteristics (Salama, 2015).

Sequential and Global Learners

The final factor for grouping the learners is whether they understand the provided information immediately or after spending a considerable amount of time. Linda Kreger Silverman (1987 as cited in Felder, 1988) discerns between these learners by calling them Sequential and Global Learners. Felder (1988) states that most curricula, course syllabi, textbooks, and teachings styles are sequential.

Learning Styles of Architecture Students

To examine Felder’s claims in addition to a study conducted by Magda Mostafa and Hoda Mostafa (2010), and to highlight the importance of paying attention to every 32 distinct types of learners, a survey based on the “Index of Learning Styles” (Felder & Soloman, 1993) including 44 questions—originally developed by Barbara A. Soloman and R. Felder—was conducted among 82 architecture students at the Faculty of Architecture and Urban Planning, Shahid Beheshti University (SBU), Tehran. Of the study population, 60 respondents completed and returned the questionnaire. There are similarities between the results of this survey and those described by Felder. For instance, Table 1 and Figure 2 show the distribution of different types of learning preferences. Also, if we accept Felder’s claims about inadequacies of teaching styles in engineering classes, around half of the students do not receive a proper education due to their characteristics. Therefore, finding a solution to fill this gap seems necessary. The survey showed that 33 percent of architecture students at SBU are sensory learners. However, most teachers use intuitive teaching methods. This gap becomes deeper when it comes to visual learners. According to the survey, 82 percent of the students who participated in the survey were visual learners whereas most engineering courses are based on the auditory material.

Table 1: Number of students in every learning style (Source: Authors).

<table>
<thead>
<tr>
<th></th>
<th>Sensing</th>
<th>Sensing</th>
<th>Intuitive</th>
<th>Intuitive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active</td>
<td>Reflective</td>
<td>Active</td>
<td>Reflective</td>
</tr>
<tr>
<td>Visual</td>
<td>Sequential</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Visual</td>
<td>Global</td>
<td>4</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>Auditory</td>
<td>Sequential</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Auditory</td>
<td>Global</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Despite the significant proportion of learners who have been left out in the current system, there is hardly any alternative for them on offer. For example, sequential learners that could not catch up with the pace of lectures, inevitably use notes and textbooks. However, these sources are not ideal ways to convey architectural concepts and data to students. A sensible
approach to tackle this is using new technologies like VR as a supplemental tool for architectural education.

<table>
<thead>
<tr>
<th>Learning Style</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing / Intuitive</td>
<td>33%</td>
</tr>
<tr>
<td>Visual / Auditory</td>
<td>67%</td>
</tr>
<tr>
<td>Active / Reflective</td>
<td>82%</td>
</tr>
<tr>
<td>Global / Sequential</td>
<td>18%</td>
</tr>
</tbody>
</table>

Figure 2. Learning styles percentage bar chart for the participants (Source: Authors).

**VR Technology and Architectural Education**

Virtual Reality can be defined as the human endeavor to remove barriers between the real world and virtual world, and it encompasses technologies that provide tools for users to interact with the simulated virtual environments. Collins dictionary defines Virtual Reality as: “an environment which is produced by a computer and seems very like reality to the person experiencing it”. Regenbrecht and Donath (1997 as cited in Portman et al., 2015) have described VR as a means of communication that takes place in a virtual space and embeds users as an integral part of that. Most of VR definitions emphasize on experiential and sensory aspects of virtual reality, and those attributes actually are the key factors that make VR a unique way of communication and learning.

Researchers have found a tremendous amount of VR applications. For instance, using VR to design cars’ interiors (Zimmermann, 2008) or remote surgeries (Marescaux & Rubino, 2005) and even training firefighters (Bailie et al., 2016). Among its numerous applications, using VR for educational purposes is a prevailing approach. Moreover, researchers believe that the compatibility of VR and educational goals provides an excellent opportunity for students and teachers. Zhigeng Pan, et al. (2006) envisions a flourishing future for global learning market due to the application of VR and Augmented Reality in e-learning.

In spite of research studies conducted for finding VR role in education, the share of architecture is not sufficient. J. Dvořák et al. (2005) state that currently VR tools are widely implemented in mechanical engineering. However, architects do not take advantage of this technology frequently in their career, and that is happening while architectural pedagogy can benefit the most from VR. One advantage of VR implementation in architectural pedagogy could be an enhancement of three-dimensional perception for students. They also confirm the educational role of VR technology in architectural education by mentioning that VR would facilitate thinking in a 3D way and by using VR students can see directly in 3D.

Some researchers suggest using VR in theoretical architectural courses. For instance, Jeff Rickel (2001) envisions a classroom scenario: ‘History students can learn about ancient Greece by walking in its streets, visiting its buildings, and interacting with its people’. In a virtual environment, humans can communicate and transfer knowledge without time and space limitations that exist in the real world while saving time and money and minimizing health risk.
Loukas Kalisperis et al. (2002) argue that using VR in design studios would boost architectural design education for students at the beginning of their professional career. They also mention that with the help VR students will be able to participate in classrooms, which is an important shift from only observing the 3D contents. This participation is not individual, in fact, by using multi-user applications and developing network features for VR application, multiple users can experience a virtual environment at the same time and also communicate and cooperate with each other while designing, presenting, and learning.

Although some engineering schools and architects have accommodated VR labs for research purposes (Portman et al., 2015), few of them use this technology as an educational apparatus. One example of VR implementation in architectural pedagogy is the one in Ball State University (Angulo, 2015). They have used a virtual simulation environment called “CAP VR Environment” in their university since 2011. Design students at Ball State University use CAP VR to analyze their design projects in terms of functionality and appearance. Antonieta Angulo states that their virtual environment with the capability of free navigation in that environment is useful for architecture students to design “signature spaces”.

In their studies, Alcinia Zita Sampaio et al. (Sampio et al., 2009; Sampio et al., 2010) introduce some applications that have been developed to be used by civil engineering students. In these applications (titled: “Didactic VR Models”, “VR Model of the Incremental Launching Method of Bridge Construction”, and “The Virtual Model of Lighting Management”) the user gets familiar with structural details and how to maintain lighting component in a house. They claim that with the options provided in those applications, the user would be able to interact with the virtual environment. For instance, in “VR Model of the Incremental Launching Method of Bridge Construction” the user has control over the process of building a bridge and can forward or rewind that process.

Another study at the University of New South Wales, Australia (Wang et al., 2015) investigates the effects of a VR application called “Situation Engine” on learning preferences of construction and architecture students. Situation Engine is designed to introduce construction to students via virtual reality technology. Wang’s survey on 245 architecture and construction students suggests that the long-held sense about positive effects of VR technology on students’ learning capability is proved in practice and long exposure to educational VR application promotes movement towards an inclination for active experimentation.

A review of previous studies indicates that although VR has been introduced or used for educational purposes, their relations with emerging theories in architectural education are not well established and their evaluations are to some extent limited. The deficiency in the previous evaluations was due to lack of objectives for the design of the educational applications and the limits in hardware and software used.

**VR Technology as a Response to Learning Theories**

To extract the characteristics of an effective educational application based on virtual reality technology, the capabilities of VR to facilitate implementation of emerging theories in architectural education is reviewed in the following sections:
Problem Based Learning (PBL) and VR

Virtual reality is a new tool that can enrich high quality-PBL and engage architectural students in deeper ways. Virtual reality can give architectural students an immersive experience to observe and take notes. Coupled with focused, inquiry-based questions, students can deepen their research. Moreover, an interactive virtual reality experience can help students become more deeply and personally engaged in topics (Gyldendahl Jensen, 2017). When choosing a question to explore for project-based learning, taking the time to experience materials related to that topic can encourage students to think more critically about their driving questions. Nabih (2010) states that a PBL approach in architectural education should be ’motivating’, ‘intellectually challenging’, and ‘include puzzling’.

Flipped learning (FL) and VR

Flipped learning requires flexible environments where students can choose when, where, what and how to study and learn. Therefore, virtual reality with its immersive and interactive nature could be used as a learning tool that could be used anywhere and anytime. To put it in the whole, VR can be used for achieving flipped learning’s goals and benefits. Wei-Kai Liou et al. (2016) have discussed that virtual reality and augmented reality can be blended in the formal classroom settings to promote active learning, which results in enhancing knowledge, comprehension and application skills of the learners.

Experiential learning (EL) and VR

The basis of experiential learning theory is in harmony with the capabilities of VR. William Winn (1993) acknowledges this by stating that the characteristics of immersive VR and the axioms of constructivist learning theory are entirely compatible. He also claims that constructivist theory provides a valid basis for a theory of learning in virtual environments. He puts forth the idea by saying that first-person experience in VR and the notion of immersion are the key contributors to the compatibility of VR with constructivism. Moreover, Zhang and Liu (2011) mention that humans learn from their surrounding environment not only by observing it but also by interacting with that.

Learning styles (LS) and VR

As Felder (1988) points out in his model, in every classification there is at least one group of learners that the current educational system fails to provide any growth opportunity for. For instance, sensory learners (at least one-third of architecture students) need sensory tools to learn, but it is challenging to find any sensory teaching methods or utensils in universities’ classrooms. VR technology, nevertheless, can provide sensory learning solutions for learners who prefer to utilize their senses to understand. The result of matching VR capacities to neglected learning styles is presented in Table 2. In this table, benefits and advantages of VR technology for architectural education are mentioned.
Table 2: Capacities of VR to be a response to different learning styles (Source: Authors).

<table>
<thead>
<tr>
<th>Classification</th>
<th>Sensing and Intuitive Learners</th>
<th>Visual and Auditory Learners</th>
<th>Inductive and Deductive Learners</th>
<th>Active and Reflective Learners</th>
<th>Sequential and Global Learners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning Style</td>
<td>Sensing</td>
<td>Visual</td>
<td>Auditory</td>
<td>Deductive</td>
<td>Active</td>
</tr>
<tr>
<td>How much current engineering education cares about them? (As noted by Felder)</td>
<td>Very Low</td>
<td>Low</td>
<td>High</td>
<td>average</td>
<td>Not determined (low*)</td>
</tr>
<tr>
<td>Characteristics</td>
<td>Prefer to experience and learning by sensing</td>
<td>Prefer visual data</td>
<td>Prefer auditory data</td>
<td>Use observations to build principles</td>
<td>Prefer to do active experiments</td>
</tr>
<tr>
<td>VR capacities to respond to the learning style</td>
<td>Simulating sensory data and providing the sense of presence</td>
<td>Providing a huge amount of reach and immersive visual data</td>
<td>Providing a huge amount of reach and immersive auditory data</td>
<td>Simulating realistic environment with accurate real-time physics and light simulation</td>
<td>Providing an interactive virtual environment</td>
</tr>
</tbody>
</table>

*although it is not directly stated by Felder, our informal surveys suggest that teachers do not include active experiments in architecture classrooms.

CHARACTERISTICS OF A VR APPLICATION FOR ARCHITECTURAL EDUCATION

Studies clearly confirm the possibilities that VR provide for enhancing learning and realizing pioneer theories of learning in architectural education. The characteristics of an ideal VR educational application are listed below. Arguably, the inclusion of all those features in a VR educational application, would enhance the learning process.

Regarding PBL, the application should be fun and motivating. VR technology is arguably fun by its nature. However, through increasing levels of immersion, adding visual effects, adding game-like tasks, and making the application more interactive, it is possible to make the system more engaging. Moreover, by simulating real events (e.g. simulating a construction site process), the system can provide an environment for learners to freely draw their own conclusions about what they have experienced. Regarding the experiential learning theory, the system should also be interactive and immersive to bring the opportunity for the learners to learn from experience. Salama (2015) acknowledges that by stating learning through experience involves not merely observing the phenomenon being studied but also doing something with it. The study of learners’ style (Table 2) also implies that the system should be interactive, immersive, flexible, and realistically simulating events. Besides, some learners prefer to decide when and where to learn new concepts and be exposed periodically to advanced concepts, hence the system should be flexible in regards to these needs.
As asserted in the literature review, some VR educational applications have been developed by researchers, but the level of interaction and immersion were limited in those cases. Alongside that, the assessment component was neglected in the previous implementation of VR in architecture and construction education. Therefore, LADUVR is trying to address those flaws.

A VR application should be flexible to become an effective learning tool considering the flipped learning theory. Although the optimum level of flexibility is not clearly investigated in any studies so far (Wanner & Palmer, 2015), studies show the flexibility would increase students’ engagement in learning (Bergmann et al., 2012; Hao, 2014; Zappe et al., 2009). Flexibility in VR education could be interpreted as learners’ decision on what type of learning materials they prefer to use and when they decide to learn. In fact, by including different learning sources such as audio, text, image, video, and 3d models the application would be flexible. Alongside that, as mentioned before, a flipped learning tool should have an assessment component. That is also possible to be included in the system due to the interactive nature of VR technology.

LADUVR APPLICATION

LADUVR is an educational VR application (developed by the authors) that presents educational material about construction and architectural detailing to users based on the characteristics extracted from learning theories mentioned in previous sections. Although similar applications have previously been developed, LADUVR arguably has advantages over them in terms of the level of interaction and content.

The Structure of LADUVR

LADUVR is comprised of three main sections: one for a step-by-step simulator for a house building process, one for facilitating an in-depth observation of architectural details, and one for practicing and learning. Below are brief descriptions of each section:

Interactable PBL/EL/LS/FL:
Learners draw their own conclusion by interacting / motivating

Immersive PBL/EL/LS/FL:
Learners draw their own conclusion by observing / Compatible with neglected learning styles

Flexible LS/FL:
Decide what, when and where to learn

Assessment component LS/FL:
Game-like assessment component
In many architecture schools (including SBU), site visits are arranged for construction courses. The idea behind this section is to simulate the sense of being on a construction site using a virtual environment and VR technology as far as possible and thereby facilitate the teaching of the building process to students. Due to the real-time simulation of light, realistic materials, and detailed 3D model of the building, users can actually experience a sense of being on a construction site. Moreover, in this section users can investigate the house building process from different views and also control that process easily just by pressing some buttons on the controllers. The controllers also provide additional information about every step of the building process in the form of imagery or audio via buttons and screen on them. For instance, by clicking on a button of the controllers a sound clip about the current step of the building process will be played.

By using this section, students are expected to understand construction stages more in-depth in an experiential fashion and also learn the time sequencing of the building process. Alongside that, this experience is completely safe and saves money and time compared with the actual construction site visit.

In-depth Observation of Architectural Details

Learning by investigating a 3D model rather than looking at a 2D representation of an architectural detail (the traditional way of presenting educational materials to the students in classrooms or books) is the obvious advantage of using VR technology. The purpose of this section is to facilitate learning of architectural details by providing an experiential learning opportunity for students using capabilities of VR technology. In this section, the user experiences the sense of being in a small virtual house and would be able to freely and virtually walk in the house. Users can interact with the virtual environment in this section; for example, to observe the details of a specific part of the building, they can click on some highlighted points, and a menu will guide them to activate some section planes. These cutting planes provide an opportunity for users to see through parts of the building and understand the architectural detailing for the corresponding section. To gain more
information users may click on “In-Depth Exploration” buttons and they would go to another level. In this level, users see an extracted part of the building including the selected detail. In this level, there are options that could help the user through the process of understanding that particular detail. For instance, the user can point at every component of the 3D model and the software plays a sound clip with additional information about that component.

Figure 5. A screenshot from “A Step-by-step Simulator for the House Building Process” section (Source: Authors).

To increase the amount of immersion, the user can activate a flashlight that can be used to light up the dark spots of the 3D model.

Figure 6. A screenshot from “In-depth Observation of Architectural Details” section (Source: Authors).
The third section is dissimilar to other sections in the sense that in this one, users practice what they have learned in the other two sections. In fact, this section is the assessment component of LADUVR. In this level, which includes some real-time simulations (lights and physics simulation), users build architectural details from the components provided in that virtual environment. These tasks would internalize their understanding and skills to work with materials. This is in line with Stice’s (1987) view that learners retain 90 percent of what has been presented to them when they struggle with that materials in action.
In 12 booths designed in circular form for this section, users build virtually 12 most fundamental architectural details (adopted from Construction-1 and Construction-2 courses in SBU curriculum). In every booth, users confront a sample of specific detail, an incomplete detail, and a table with some architectural components on that (bricks, steel profiles, insulation materials, etc.). The users are expected to use those components to finish the incomplete detail. If everything goes correctly, a message notifies users that the task has been accomplished; otherwise, they should correct their mistakes. Alongside the samples that exist in every booth, users carry a screen on their controller that shows additional information about the particular detail presented in the test. The most interactive section of LADUVR is “Practice and Learn” therefore a considerable amount of coding was required to accomplish this section’s aim.

**Challenges and Stages of the Work**

In this section challenges in the process of developing any educational application like LADUVR are reported. This interdisciplinary project demands a wide variety of skills. To elaborate on this, three different types of tasks have been done by the authors to develop LADUVR. These tasks can be categorized as “Designing and Providing Contents”, “Designing the Interface” and “Coding and Programming”.

**Designing and Providing Contents**

The most challenging section for developing any educational application is providing appropriate contents. To accomplish this, numerous studies have been conducted to select valid and suitable architectural details for presenting to architecture students. All contents of LADUVR are chosen with reference to two courses (Construction-1 and Construction-2) at SBU. They are both undergraduate courses, and play a key role in teaching construction and architectural detailing. Some of the contents are also chosen with reference to the book “Understanding Architectural Details” by Emma Walshaw (2015).
The next step was to convert all the chosen materials to VR optimized 3D models. This step was the most time-consuming part of the project and in this process a lot of modeling, texturing, and 3D model optimization was carried out to ensure that the final application would run smoothly and would not cause any problem including motion sickness for users. All 3D modeling on the computer was carried out using Sketchup Pro for Windows. After modeling all the contents, 3D models have been imported to the Unreal Engine. Not until we have the fully detailed 3D models of architectural details were we able to develop a VR application, because in this kind of media, the user would inspect 3D models in a virtual environment from almost every possible view and even a single minor error in the 3d model could ruin the learning process and would cause distraction and even motion sickness.

![Image of a modeled house](Source: Authors)

Figure 10. The house modeled to represent architectural detailing contents in LADUVR (Source: Authors).

**Coding and Programming**

There are major issues with this stage, as programming is not the normal practice among architects and their teachers (in this case coding for a VR application). To overcome this...
problem, effective and relatively easy-to-use tools have been introduced in the game production industry: The Game Engines. Game Engines are powerful tools for developing any kind of application because they provide a wide variety of features for the developers including accurate light simulators, physics simulators, some templates and pre-coded assets for producing VR application. Alongside those tools, Visual programming language (VPL) is contrived in some of those game engines. VPL is a programming language that uses graphical elements and figures to develop a program. The user-friendly interface of VPLs makes it a useful tool for people who are not familiar with the traditional way of coding and want to develop educational applications. Unreal Engine is one of the most powerful free game engines available for developing VR applications and also includes its own node-based visual programming language called Blueprints.

![Figure 11. A sample of VPL coding done for LADUVR that controls the visibility of components of Test no.1 in “Practice and Learn” section (Source: Authors).](image)

To finalize the production of LADUVR, significant amounts of optimization and bug fixing were found necessary. In fact, to make a VR application, it is crucial to make every part of the application so efficient that it would run at least in 60 frames per seconds to reduce the chance of motion sickness occurrence. In case of not being able to fulfill that requirement, the VR experience would fail. Some tricks and optimizations for VR applications that have been used in LADUVR are discussed in a study by Hii Jun Chung (2007).

### Designing the Interface

An interface is an essential part of any application, and when it comes to VR, it becomes more crucial to design an interface compatible with the capabilities of VR and expectations of the users. LADUVR’s interface (like the other components) has been designed with much trial and error to make sure that the users would be comfortable while using this application.

In LADUVR, the user can interact with the interface of the application using two physical motion controllers. By pointing at specified parts of the virtual environment and clicking on the keys of motion controllers, the user could interact with the application. The same menu also provides information about how to use application and additional information in every section.
IMPLEMENTATION AND EVALUATION

The next step after the feasibility study and introduction of LADUVR was the implementation and evaluation. The evaluation was performed in the Architecture department, Faculty of Architecture and Urban Planning, Shahid Beheshti University, through a pilot study carried out to measure the effectiveness of LADUVR on a small group of architecture students.

The equipment and facilities needed for this study included a virtual reality head-mounted display (HTC VIVE), a room with minimum of 3 meters by 2.5 meters of free space (The recommended minimum space for using HTC VIVE is 2 meters by 1.5 meters, however, interacting with LADUVR’s interface in that amount of space is challenging.), and a personal computer with a high performance graphic processor. Due to satisfactory levels of immersion that HTC VIVE provides and its reasonable price, LADUVR is specially designed to work with this specific HMD. However, LADUVR is modifiable to work with other HMDS.

After providing all the requirements, students who had completed Construction 2 or Construction 3 courses within the last year were called to participate through an announcement. Eight students were randomly selected from volunteers for the meeting session and the interview. Importantly, half of the interviewees had significant experience of being in a real construction site.

At the scheduled meeting time, instructions were given to users to feel comfortable with the application’s interface. Each participant experienced LADUVR in a fixed amount of time (about 15 minutes). At the end of the experience, all were interviewed. Greg Guest et al. (2006) suggest that considering the concept of “Saturation”, within the first six interviews basic patterns in the result would be exposed and after 12 interviews enough saturation could be reached. It was found safe to assert in this case that eight interviewees would suffice.

Moreover, participants were interviewed by asking 11 questions to compare their experience of LADUVR with what they have seen in the current construction course in the university. Finally, a question about ‘How well do you remember what you have learned in your experience with LADUVR?’ sent to participants and they sent back their answers. The results of this preliminary study suggest that students believe LADUVR could help them to understand architectural detailing better in a flexible, interactive, and immersive environment. As a matter of fact, LADUVR was found to be effective, efficient and attractive for most students. Detailed results of this evaluation are as follows:
Level of Flexibility

We asked participants ‘do you think that the level of flexibility that is provided in LADUVR is more than actual construction courses? or not? And do you think it would enhance your learning progress?’. Almost all the participants implied that this application is far more flexible compared to traditional classes at the university because they have an opportunity to decide when, where, and what to learn. They also asserted that shifting from one source of learning (e.g. a 3D model of a construction detail) to another source (e.g. recorded videos of a construction task) is really easy and it really makes the application engaging. Moreover, about half of the participants asserted that they think this level of flexibility would help them to proceed their learning process more effectively, however, the other half claimed that they prefer to have a guideline or a teacher beside them while using LADUVR to guide them what to watch first and what to do next. One of the interviewees also stated that she cannot follow the learning process without having a linear learning path. It is possible that the diversity in the reactions to the level of flexibility in LADUVR is related to the learning styles of the participants.

The Assessment Component

Participants were asked to tell their opinion about the assessment section of LADUVR (Practice and Learn section). Most of the interviewees were satisfied with this section in terms of the level of engagement, however, five participants claimed that they prefer more types of assessments tasks and it is a good idea to add options to access previous results of the tests from the internet and compare that to other students. Although the authors of this article are aware of the limitations and deficiencies of this section (e.g. not providing personalized test according to the users’ learning styles due to the challenging nature of coding), the general opinion about the idea of testing learners’ knowledge through a series of game-like tasks was very positive.

Clarity of the Learning

To find out the quality of information that LADUVR offers, we asked the participants how they evaluate the clarity of data presented in this application. There was a clear consensus on the higher clarity of the data that is transferred through LADUVR compared to actual construction courses due to a real 3D presentation and real scale of objects presented there. Participants declared that in the first section of LADUVR (A Step-by-step Simulator for the House Building Process) there were some missed steps in the process of building and they suggested that by increasing the number of steps they would understand the whole process more precise. In addition, all the participants evaluated the clarity of data for the two next sections excellent. Participant also said that lack of perceiving texture and weight for detail components put this application a level below a real construction site experience.

The Quantity of Information Conveyed

The interviewees agreed that the amount of information perceived during this event (regarding the exposure time) is higher than what teachers offer during construction classes. However, some interviewees believe that in some sections of LADUVR there is more information than their capacity to learn in one session.
Transferring Knowledge to Others

A good measure to understand how well a topic is learned is to examine the ability to transfer that data to other people. So, all the interviewees were asked about this issue. Almost all of them believed that due to the higher level of clarity in data presentation compared to traditional construction courses, they would be more successful to transfer data to classmates and colleagues in a linguistic way. It is noteworthy to mention that a portion of participants in the interview was concerned about being able to draw 2D presentations from what they had learned in LADUVR.

Ability to Transfer Knowledge into Practice

Considering the fact that the presented data were clearer compared to those of traditional learning, interviewees declared that it would be easier to use that information in a real scenario. However, they stated that there are some skills (e.g. how to implement a brick wall completely vertical) that users cannot learn in applications like LADUVR. Some interviewees believe that LADUVR is more efficient for getting a grasp of construction. In contrast, some stated that gaining experience through working in real construction sites is a better way for learning tips and tricks.

Reviewing Learned Materials

Participants in the interview mentioned that they have to acquire VR hardware to use LADUVR at home or school for relearning purposes. In fact, the present costs of equipment needed for realizing virtual reality is an obstacle to implementing VR technology in architecture schools. Moreover, users prefer to use notes and books for relearning and reviewing educational materials.

Attractive or Boring

We asked the participants' opinion about how much they found LADUVR an interesting way of learning. All the participants described the experience as far more attractive than the traditional alternative. Most interviewees also stated that they were surprised how fast the testing time passed. They found the whole experience enjoyable because of the possibility to interact with materials. however, a small number of applicants doubted whether the experience remains as attractive as the first time on the next occasion.

Replacement for Teachers

Although a small portion of interviewees stated that this application could replace traditional education, most of them believed that this application is a supplement for traditional education.

Remembering After a Week

After a week we sent the participants a question about how much they remember what have learned in their experience with LADUVR. Almost all the participants stated that they remember what they have learned in their first session. Moreover, they added that they have
maintained a visual model from presented materials in LADUVR since the testing time. However, some interviewees stated that they remember the overall concept better than minute details. One of the interviewees also added that during the testing of the third section of LADUVR, he spent more time on getting comfortable with learning interface rather than spending time to learn architectural detailing.

Advantages of LADUVR

Some advantages of using LADUVR in architecture pedagogy over the traditional way of learning architectural details from the perspective of the participants are listed below:

- **3D Instead of 2D**: Perceiving information similar to when people look at real objects (including all information about dimension and scale) is possible in LADUVR. Representation of architectural details in papers and regular monitors are two-dimensional while by using VR technology, learners perceive the real scale of architectural components in a three-dimensional environment.

- **Interactive**: The most important factor that distinguishes this application from other traditional presentations of educational materials and even other VR applications that were mentioned in previous paragraphs, is the level of interaction that is provided in LADUVR.

- **Immersive**: The sense of presence in a virtual world could facilitate the mind to focus on learning instead of imagining. The realistic environment of LADUVR with its real-time reflection and lighting calculations provides a high degree of immersion.

- **Control over Time**: It is in actual life experiences that people learn from natural phenomenon. In most cases, the process of natural phenomenon cannot be controlled or rewound, however, in virtual environment users have control over time. For instance, in “A Step-by-step Simulator for the House Building Process” users can rewind or forward the building process.

- **Additional Multimedia Information**: Options for presenting extra audio, video, and pictures while inspecting the 3D model of the details is a notable feature of LADUVR. For example, in this application, a sound clip would be played to guide how to implement a metal deck just by clicking on the metal deck’s 3D component.

- **Cost Less Time and Money**: In spite of the initial investments for developing the application, cost of implementing LADUVR compared to preparing similar real-life situations, for example, a real construction site visit, is less.

- **No Health Risk**: Being on a real construction site presents a safety risk to the attendees; however, the virtual environment eliminates this risk.

CONCLUSION

Undoubtedly, VR technology will play a crucial role in the future of e-learning and the way humans will think about education. Alongside other sub-fields of architecture, teaching construction and architectural detailing could benefit most from this new technology. Furthermore, there are many challenges in architectural education that can be addressed through VR. For instance, according to a survey conducted in this study about half of the architecture students do not receive the education in the way they are better at receiving. In response, an educational application based on VR technology called LADUVR has been
designed and developed, an interactive and immersive experience which is fun, flexible, and has an assessment component. The grounds for this application are based on new theories of education in architecture such as PBL, EL, FL and learning styles theory. To elaborate on this, an educational VR application should be flexible, interactive, immersive and comprise an assessment component to: 1) put an end to the neglect of some learning styles, 2) to be a tools for realizing blended learning and 3) promoting problems based learning, as well as 4) being a tool for providing experiential learning opportunity in classrooms.

Through developing LADUVR, challenges and advantages were identified. The first challenge bear to implement VR technology for educational purposes would be preparing contents that meet requirements for VR. Moreover, like a video game, a VR application without enough interaction would be a one-way media and could not motivate learners to use this flexible source of learning. The third challenge is translating all the plans and contents to computer language. Although this would require the knowledge of coding, new tools for developing applications like VPL could help researchers that are not expert at coding.

Finally, the implementation of LADUVR was put to test as part of this work. A pilot study of LADUVR was conducted with the results indicating that learning construction through virtual reality has notable benefits: 1. Facilitating blended learning and problem based learning’s goals by being a flexible learning tool, 2. learning knowledge more efficiently, 3. improving recalling the information for a longer period of time, 4. providing an experiential learning tool that could facilitate transferring perceived knowledge into practice, 5. providing assessment component by being interactive, and 6. facilitating conveying data to classmates and colleagues are potential advantages of LADUVR.

However, interviewees believe providing equipment for using VR application in architectural classrooms is a serious challenge. Alongside that, participants in the pilot study declared that there is less probability for LADUVR to replace teachers and classes in the near future. In fact, it is better to use LADUVR as a supplemental tool for education.

**OPEN POSSIBILITIES**

VR world is just at the beginning of its era; many hardware and software that would enhance VR experience are introduced every day. But the interdisciplinary nature of developing VR applications is an immense challenge in the way of using maximum capabilities of this new technology in education and e-learning, and how to implement that in architectural pedagogy could be subject to future research studies. From the authors’ point of view, the following topics could be open possibilities for further studies.

- More research is required to determine the efficacy of these kinds of applications and how to implement them in actual classrooms.
- Further studies can be done on the relationship of other educational models with VR technology.
- Designing and evaluating VR educational application that have adaptive features for different users with different learning preferences. An adaptive and intelligent educational systems which provide an alternative to the traditional “one-size-fits-all” approach in education (Eissa & Lee, 2008).
- Design VR/AR educational application that helps students connect learning with their life-world experiences.
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