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# Context-Aware Mobile Augmented Reality Visualization in Construction Engineering Education

Arezoo Shirazi

*University of Central Florida*

CONTEXT-AWARE MOBILE AUGMENTED REALITY VISUALIZATION IN
CONSTRUCTION ENGINEERING EDUCATION

by

AREZOO SHIRAZI
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# ABSTRACT

Recent studies suggest that the number of students pursuing science, technology, engineering, and mathematics (STEM) degrees has been generally decreasing. An extensive body of research cites the lack of motivation and engagement in the learning process as a major underlying reason of this decline. It has been discussed that if properly implemented, instructional technology can enhance student engagement and the quality of learning. Therefore, the main goal of this research is to implement and assess effectiveness of augmented reality (AR)-based pedagogical tools on student learning. For this purpose, two sets of experiments were designed and implemented in two different construction and civil engineering undergraduate level courses at the University of Central Florida (UCF). The first experiment was designed to systematically assess the effectiveness of a context-aware mobile AR tool (CAM-ART) in real classroom-scale environment. This tool was used to enhance traditional lecture-based instruction and information delivery by augmenting the contents of an ordinary textbook using computer-generated three-dimensional (3D) objects and other virtual multimedia (e.g. sound, video, graphs). The experiment conducted on two separate control and test groups and pre- and post- performance data as well as student perception of using CAM-ART was collected through several feedback questionnaires. In the second experiment, a building design and assembly task competition was designed and conducted using a mobile AR platform. The pedagogical value of mobile AR-based instruction and information delivery to student

learning in a large-scale classroom setting was also assessed and investigated. Similar to the first experiment, students in this experiment were divided into two control and test groups. Students' performance data as well as their feedback, suggestions, and workload were systematically collected and analyzed. Data analysis showed that the mobile AR framework had a measurable and positive impact on students' learning. In particular, it was found that students in the test group (who used the AR tool) performed slightly better with respect to certain measures and spent more time on collaboration, communication, and exchanging ideas in both experiments. Overall, students ranked the effectiveness of the AR tool very high and stated that it has a good potential to reform traditional teaching methods.

To my beloved **Family**,

My mother who taught me how to live and love,

My father who taught me how to forgive and move on,

And, my brother who taught me how to be a sister!

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acknowledged. Any opinions, findings, conclusions, and recommendations expressed in

this Thesis are those of the author and do not necessarily reflect the views of the EiF.

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# CHAPTER 1: INTRODUCTION

## 1.1  Thesis Statement

The new generation of students is technology savvy with high knowledge of and interest in social media, mobile technologies, and strategy games. At the same time, existing instructional and training techniques in construction and civil engineering do not take full advantage of the latest technology advancements. Hence, the hypothesis of this research is that instructional technology coupled with a strong pedagogical methodology can bridge this gap by improving the quality of student learning [1, 2]. To this end, this research aims at the design, implementation, and assessment of a new technology-based pedagogical methodology based on augmented reality (AR) visualization to support the prospect of a more engaging learning experiment for construction and civil engineering students and instructors.

## 1.2  Research Motivation

According to the National Academies Press (NAP), during the past two decades, students perusing bachelor's degrees in science, technology, engineering and mathematic (STEM) disciplines decreased by 18% in the United States [3]. Moreover, only 23% of college freshman students declared a STEM major and just 40% of those that chose STEM,

received a STEM degree by the end of their studies [4]. Very recently, the United States ranked 17th amongst the developed countries in the proportion of college students receiving bachelor's degrees in science and engineering [3]. These and several other statistics have motivated researchers to look for the underlying reasons of and the rationale behind this decline.

Some researchers discussed that the relatively high upfront monetary investment necessary to earn an engineering degree may be a setback to many students [5]. However, this may not be necessarily true since figures show that the salary of a typical engineer is much higher than many other majors [6]. Some educators have argued that the decision to pursue a STEM major is based on two factors: (1) personal capabilities and preparedness to succeed, and (2) desire to pursue that discipline. They believe that success in attracting more students into the STEM fields depends on how well educational institutions address both components [7]. However, other researchers indicated that the problem is not attracting students into the STEM fields, rather it is retaining them there throughout their studies and engaging them in the learning process [8].

To many students who are pursuing degrees in STEM, instructional techniques that heavily rely on traditional methods (e.g. note taking, handouts, memorization) to convey basic knowledge and skills about fundamental theories and applications are considered obsolete and not engaging. Outdated and poor teaching methods, disconnection between students and technology, and lack of hands-on experiments are among important reasons

that keep students away from pursuing STEM disciplines [9]. Therefore, finding a way to facilitate the transformation of difficult (and often boring) course topics into a more engaging and easy-to-understand learning experience was the underlying motivation for this research.

## 1.3  Background Survey

An academic survey was conducted on 241 junior-level students of civil, environmental, and construction engineering at the University of Central Florida (UCF) in 2012-13. Results indicated that 92% of respondents identified themselves as visual learners. In particular, this group agreed to the statement that "I learn better when the instructor uses 2D/3D visualization or multimedia to teach abstract engineering and scientific topics" (Figure 1.1). Moreover, 54% claimed that they learn better while working in a collaborative setting (e.g. working in a team) where they can play a role in the learning process (Figure 1.2). Figures 1.3 describes the gender information of the participants and their academic majors. The complete survey questionnaire is presented in Appendix A.
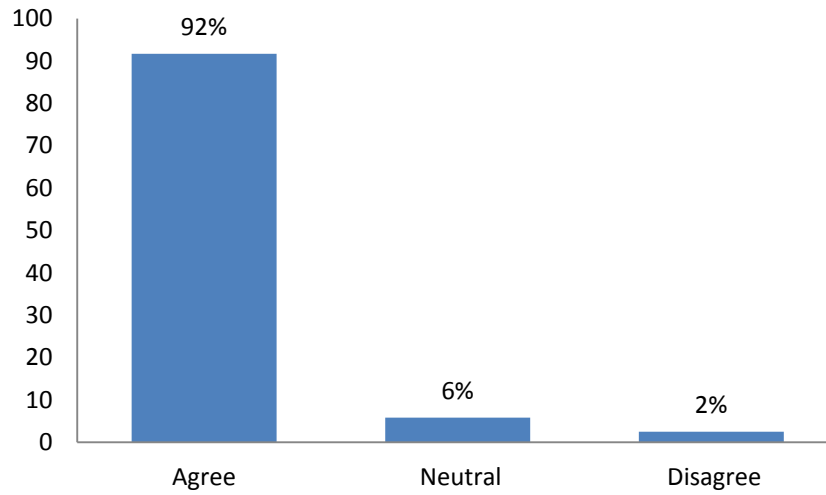
Figure 1.1: A solid majority of students identified themselves as visual learners.
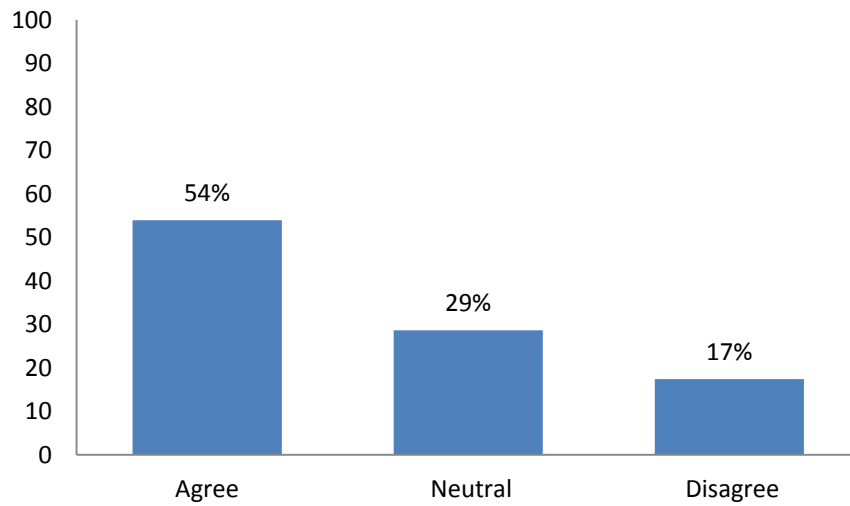


Figure 1.2: Students claimed that they learn better while working in a collaborative setting.
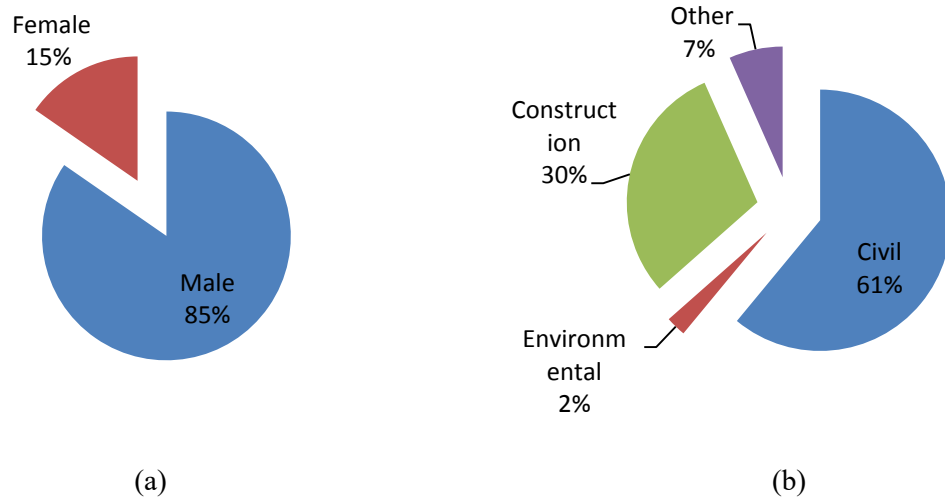
Figure 1.3: (a) Gender distribution, and (b) academic major distribution of survey respondents.

Several studies supported the positive effect of using portable electronic devices (PED) (e.g. laptop, smartphone, or tablet computer) on student learning and engagement [10, 11]. However, clearly not all academic institutions and universities are financially capable of providing high-tech devices and equipment to students. Therefore, one major concern in this and similar studies is the issue of affordability. For this reason, survey respondents were also asked to indicate if they already own a technology-enabled device that can be readily used in the classroom; 93% declared that they own either a smartphone or a tablet device or both (Figure 1.4), and can easily use it in their daily activities. In addition, results of a separate study conducted in 2013 showed that 89% of high schools students and 50% of 3rd through 5th grade students in the United States have access to internet-connected smartphones. Moreover, the results showed that 50% of high school student have access to tablet computers and 60% have laptops [12].
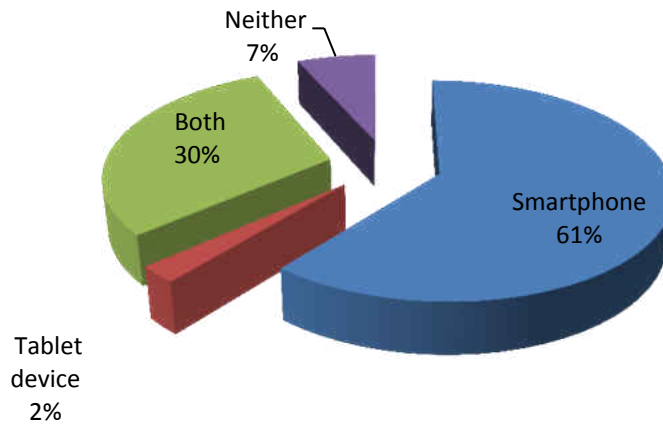
Figure 1.4: A large population of students indicated that they had a mobile device in their possession.

The fact that most students identified themselves as visual learners coupled with the large population of students who have a mobile device in their possessions, motivated the author to pursue the use of AR visualization technology that can be effectively integrated into mobile computing platforms.

## 1.4  Research Contributions

Previous research has highlighted the positive effect of integrating technology into higher education on complementing, supplementing, and enhancing the components common to any instructional model [13, 14]. Along this line, some studies have concluded that the latest technology such as PEDs have become an integral part of a typical college student's learning toolbox. While some may argue that such tools can be a source of distraction [15], they can also provide an opportunity for engaging students, if used properly [10]. Some studies illustrated how mobile technologies can be used to (a)

facilitate guided participation among undergraduate engineering students within classes, and (b) teach graduate students in instructional technology to design for guided participation [16, 17].

Ultimately, the goal of all such research projects has been to enable educators to use technology-enhanced learning beyond just the desktop or classroom computers and towards making value-adding links between information and communications technology (ICT) and other classroom activities [18]. Even if such technologies are not yet user friendly and completely affordable, the pedagogy underlying these approaches can be used as a source for introducing ICT to students for teaching and learning purposes.

Among several classes of digital technology, using virtual learning applications may result in an efficient and effective learning [19]. More recently, a growing number of schools and educational institutions have shown interest in adopting such technologies in order to create more productive educational environments. In particular, immersive virtual reality (VR) and AR are becoming standard components of the STEM curricula [20, 21] as they help teachers be more effective when explaining abstract topics, while providing students with a means to collaborate on a common problem which ultimately strengthens their teamwork skills, as well as their ability for critical thinking and effective communication. This Thesis presents the findings of a research project which aimed at exploring the potential of mobile context-aware AR in STEM education. For proof-of-concept experiments and to validate the applicability of the developed methodology, different scenarios were designed and implemented in construction and civil engineering

domains. However, the outcome of this research is sought to be generalizable and thus, the application domain could be ultimately expanded to other STEM disciplines.

## 1.5  Research Objective

The overall objective of this study is to *design, implement, and asses a context-aware mobile AR framework to enhance the instructional quality of construction and civil engineering curricula in higher education.* In order to achieve this objective, the following research tasks were identified and successfully completed:

- Investigate the requirements, and design and implement a functional context-aware mobile AR platform that allows students to access visual information stored in an online domain.

- Design and conduct a comprehensive experiment to assess the extent to which an undergraduate engineering course titled "Construction Methods" can be enhanced by augmenting an ordinary textbook with additional visual information using a context-aware mobile AR tool (CAM-ART).

- Design and conduct a comprehensive experiment to assess the extent to which student performance in a model building design and assembly project offered as a learning module in an undergraduate engineering course titled "Civil Engineering Measurements" can be improved through AR content delivery.

- Collect and analyze student performance data using different classroom assessment and evaluation techniques to evaluate the pedagogical value of the developed methodology to improve the quality of student learning.

- Collect and analyze student feedback data using well-known statistical analysis techniques such as NASA task load index (NASA-TLX) to assess the effectiveness of the developed methodology compared to traditional teaching techniques.

## 1.6  Organization of the Thesis

The following Chapters of this Thesis are shaped around the concepts, details, and implementation of the research tasks listed above. This Thesis is divided into six Chapters.  In particular:

- Chapter 1: Introduction – This Chapter contains the Thesis statement, identified gaps that motivated this research, preliminary survey results in support of the research prospect, a brief narrative of the overall research approach, and a description of objective and tasks defined and accomplished in this project.

- Chapter 2: Current State of Technology Integration in Construction Education – This Chapter presents a review of previous related research and studies in the realm of the application of instructional technology in construction and civil engineering, visualization and information delivery platforms, as well as supportive learning theories in technology-aided education.

- Chapter 3: Mobile Augmented Reality Framework – This Chapter describes the structure and design of the developed AR visualization framework and presents detailed descriptions and technical aspects of the open source web-based AR platform used in this research.

- Chapter 4: Experiment 1: Enhanced Training Using Context-Aware Mobile Augmented Reality – This Chapter contains information about the design, implementation, and pedagogical assessment of results for the first classroom experiments. In this experiment, the contents of an ordinary textbook was enhanced using computer-generated three-dimensional (3D) objects and other virtual multimedia (e.g. sound, video, graphs), and delivered to students through an AR application running on their smartphones or tablet devices.

- Chapter 5: Experiment 2: Technical Content Delivery Using Mobile Augmented Reality – This Chapter contains information about the design, implementation, and pedagogical assessment of results for the second classroom experiment. In this experiment, technical information was delivered in AR to students on their mobile devices by a virtual instructor during a model building design and assembly project.

- Chapter 6: Conclusions and Future Work – A discussion about the identified gaps in knowledge and the developed methodology for addressing these gaps is presented in this Chapter and future research for further development of the presented pedagogical framework is described.

# CHAPTER 2: CURRENT STATE OF TECHNOLOGY INTEGRATION IN CONSTRUCTION EDUCATION

In Chapter 1, a general introduction to the research was presented and the motivation, results of background survey, potential contributions, research objective, and project tasks were described in details. In this Chapter, a comprehensive review of recent research efforts and current demands in instructional technology in construction education such as visualization and information delivery platforms, as well as supportive learning theories in technology-aided education will be conducted. The goal of this Chapter is to put the presented work into the proper context and demonstrate its potentials in addressing some of the new challenges faced by the construction and civil engineering educators and students.

## 2.1  Recent Technology Advancements in Construction and Civil Engineering

As a result of their inherent dynamic characteristics and the evolving nature of the environment in which they are taking place, architecture, engineering, and construction (AEC) projects can significantly benefit from the integration of advanced information technology into conventional planning, execution, and inspection techniques. A growing number of studies have investigated the potential of using technology innovations in construction engineering [22-26]. For instance, building information modeling (BIM) is one of the most promising recent technologies successfully implemented in AEC domains. BIM allows project planners to construct and maintain an accurate virtual

model of a building or facility throughout its lifecycle. This virtual model can be used as a repository of contextual information for planning, design, construction, and operation of an AEC project. It also helps architects, engineers, and constructors visualize what is to be built and identify any potential design, construction, or operational conflicts before committing real resources on the jobsite [27]. Hence, BIM can enhance conventional planning and estimation methods during preconstruction, construction, and maintenance stages levels.

Indoor and outdoor automated data collection techniques are among other technologies that have received credibility in construction and civil engineering over the past several years as they facilitate different tasks such as resource management, quality control, and workflow monitoring [28]. For this purpose, numerous technologies such as radio frequency identification (RFID), global positioning system (GPS), and ultra wide band (UWB) have been used to facilitate indoor and outdoor real time data collection and automated field progress monitoring [29-32]. Moreover, visualization platforms such as VITASCOPE [33] and ARVISCOPE [34] were developed recently to generate realistic simulation-based visualizations of construction operations. In addition, the use of personal digital assistant (PDA) devices, smartphones, and other mobile computing platforms has become increasingly ubiquitous in many workspaces including construction jobsites and field offices [35].

In summary, the AEC industry has been witnessing a rapid growth in technology advancements in areas such as modeling, sensing, and visualization. This has helped

project planners and field personnel to more accurately predict project cost overruns, resource conflicts, and schedule delays, while preventing (to the most extent) future occurrences of such undesirable situations in a more timely manner [36].

## 2.2 Augmented Reality (AR) Visualization in Construction and Civil Engineering Research and Education

Among several state-of-the-art computing platforms available to the AEC industry, context-aware visualization is by far one of the leading technologies with very high potential to guide site personnel and project decision-makers through the construction and maintenance of infrastructure projects [37, 38]. Several research studies have demonstrated the potential of virtual reality (VR) and AR in different contexts such as visualization aid for subsurface and underground data visualization [39], architectural design [40], infrastructure field tasks and urban planning [41, 42], displaying abstract engineering concepts [43], and design perception [44]. AR visualization in particular has been recently drawing more attention since it can provide on-demand visual information to support tasks such as inspection, coordination, interpretation, and communication in building and facility engineering and management [45]. Therefore, several researchers have attempted in the past to develop AR applications for AEC. For example, Webster et al. [46] used an AR system to overlay graphics and sounds on a person's vision and hearing to improve methods for the construction, inspection, and renovation of architectural structures. Roberts et al. [39] presented an AR system that allowed users to see underground features such as geological structures, pipes, and zones of contaminated

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land. This system helps avoid accidents that may damage underground utilities during excavation. In another study, researchers built an AR prototype to superimpose graphical objects representing different project activities to visually simulate the operations involved in a future project [47]. In addition, researchers designed and implemented a 4-dimensional (4D) AR system for construction progress monitoring with the goal of identifying, processing, and communicating discrepancies between actual and as-planned performances [32]. There have been also AR tools to help equipment operators navigate inside congested workspaces to complete certain tasks [48]. Also, Golparvar-Fard et al. [49] implemented mobile interactive AR for use during design and construction.

Dunston [45] discussed a number of technical issues associated with the application of AR systems in construction including displays, tracking, and calibration. Chen and Wang [50] presented a framework for multi-disciplinary collaboration, discussed that tangible AR is a suitable system for design collaboration, and illustrated the need for integrating tangible user interfaces (TUIs) and AR systems. Furthermore, Wagner and Schmalstieg [51] presented a 3D AR navigation application that guides a user to a desired location inside an unknown building. A comprehensive review of visualization applications in construction was presented by Kamat et al. [52] where the state-of-the-art in discrete-event simulation (DES)-based AR and VR visualization as well as the application of AR visualization in field progress monitoring were reviewed [34].

In addition, within the past few years, AR applications have been developed and implemented to assist in collaborative education [53-55]. These types of applications can

be used to bring virtual models of project entities or hard-to-access objects such as heavy and expensive instruments into classrooms, simulate hazardous or unsafe scenarios such as construction jobsite operations, or visualize hard-to-explain concepts such as how different tools and equipment function [56]. Regarding the educational and training aspects of AR in construction, Dong and Kamat [57] presented the design of a robust general-purpose mobile computing framework that allows users to create complex AR visual simulations. More recently, a framework for collaborative AR-based modeling environments for construction engineering was introduced in which location-aware AR was integrated into the teaching and learning experience [58].

AR and other advanced visualization applications have been also used for educational purposes in construction training and sustainable design [59, 60]. For instance, it has been commonly theorized that VR and AR assistance in an assembly task could be helpful and increase productivity [61, 62]. Different AR applications enabled engineers to design and plan a product assembly and its assembly sequence through manipulating virtual prototypes in a real assembly workplace [63].

## 2.3  AR and Education

Several researchers have reviewed the literature describing the impact of technology on learning, and concluded that if properly used, instructional technology can have great potential in enhancing students' and teachers' performance [64, 65]. It was discussed that across people and situations, interactive simulations are more dominant for cognitive gain

outcomes [66]. However, depending on the domain and audience, the results are slightly different. For example, male and female students have shown different attitudes towards working with pedagogical computer games and interactive simulation programs [67, 68].

There are four types of virtual-real environments: pure VR, augmented virtuality (AV), AR, and reality [69]. In VR, the surrounding environments are completely digitalized. In AV, real objects are embedded into virtual ones. AR overlays 3D computer-generated objects and text on top of the real world environment. In this case, users are also allowed to see the real world instead of completely being immersed in a pure virtual environment. Therefore, AR supplements reality, rather than completely replacing it [70]. Considering the technological point of view, AR applications must fulfill three requirements which are as followed [71]:

1. Combining real and virtual computer-generated contents by adequately superimposing the virtual world on top of the real world,
2. Enabling accurate registration of virtual and real objects in a 3D space, and
3. Providing a platform for real time interaction.

Although VR has been used during the past several years in science, technology, engineering and mathematic (STEM) education, researchers predict that very soon, AR will supersede VR in terms of widespread use and educational impact [72]. Studies suggest that many people are still uncomfortable with navigating around and interacting with a fully virtual world [73]. To this end, one of the advantages of AR is that it does not completely eliminate the real world from a user's experience, and hence, users have a

more realistic sense of presence. In addition, AR provides a convenient interface for constructivism learning, spatial understanding, discovery-based learning, and social interaction, while allowing users to learn through making mistakes without having to worry about real world consequences [74]. AR also enriches the repertoire of learning opportunities and helps meet the challenge of "science for all" which refers to providing diverse and heterogeneous population with science education opportunities [75].

While researchers are still working on the psychological aspects of the integration of AR in education, several studies have so far validated the technological effectiveness of AR in the learning process [76, 77]. Recently, several handheld AR learning systems have been devised to explore the effectiveness of this technology in learning. For instance, Billinghurst [78] proposed a handheld AR educational application in which a virtual character teaches users about art history. Moreover, AR has recently been introduced in new application areas such as historical heritage reconstruction [79], training of operators of industrial processes [80], system maintenance [81], and tourist visits to museums and other historic buildings [82]. Several researchers have designed and developed AR applications such as CONNECT [83], CREATE [84], Centre to Go (SCeTGo) [75], and ARiSE [85] in order to improve educational methods. They have all worked on the capability of AR to develop new tools, based on 3D interactions with users, and to make different concepts easy to learn. As far as engineering education is concerned, previous studies used AR to enhance spatial abilities, an important component of human intelligence in math and geometry. For instance, Construct3D is a 3D geometric

construction tool specifically designed for mathematics and geometry education [86]. AR-Dehaes is another application for improving spatial abilities of engineering students based on simple technical drawing concepts [87]. In another research, an educational AR application was used for mechanical engineering teaching that allowed users to interact with 3D content using web technology and AR-VR techniques [88]. Furthermore, one of the recent AR educational applications is the "MagikBook" [89]. This AR interface, uses regular books with AR markers. Students can read the text and look at the images of the book in a regular way and also use an AR display to see more 3D virtual models appearing on top of the pages, thus immersing in an attractive learning methodology which smoothly transport users between virtual and real worlds.

In architecture and construction education, there have been several studies that aimed at using simulation and multimedia as well as digital gaming for students to understand the components and processes of building technology and sustainable design [60, 90-93]. For instance, MACE is one of the mobile AR learning experiences designed for architecture education. In this project, location-based services on mobile devices was used to provide students with geological information [75]. There have also been few research attempts at using AR-enhanced books and tabletop AR for student learning and training purposes [94, 95].

## 2.4  Supportive Learning Theories and Human Learning System

Learning is defined as a change in knowledge attributable to experience [96]. However, a change in knowledge can never be directly detected; rather it can be inferred by observing a change in the learner's behavior. This can be achieved through observing how a learner answers some questions or responds to different stimuli [97]. According to the Cambridge Handbook of Learning Sciences [98], there are several contrasts between deep learning and traditional classroom practices that have dominated schooling for decades [99]. Among others, these include the disconnection between class materials and what students already know, and understanding ideas that are not straight from the textbook.

Researchers have suggested that instrumental aids are one of the effective ways of controlling human learning [100]. Some believe that even if a teacher devotes all her time to one student, her inadequacy is multiplied manifold when she must serve as a reinforcing device to many students at once. Therefore, if a teacher is to take advantage of recent theoretical advances in the learning science, she must also have the help of some peripheral devices to augment her control over the learning mechanism. On the other hand, eliminating the teacher also has its own disadvantages since without specific guidance from teachers students may fail to understand the conceptual part of the lessons. Consequently, having a pedagogical tool to supplement teachers' guidance would be an ideal solution to effective learning.

However, prior to designing any learning tool, it is important to know how the human information processing system works. There are three fundamental principles in the science of learning, also known as cognitive theories of multimedia learning [101]: (1) dual channels which states that people have separate channels for processing verbal and visual material, (2) limited capacity which means people can process limited amounts of material in each channel at any given time, and (3) active processing which indicates that meaningful learning occurs when learners are engaged in appropriate cognitive processing during the learning process. The cognitive theory of multimedia learning provides a basic description of how the human information processing system works. As shown in Figure 2.1, there are three different memory stores, known as (1) sensory memory which holds information in the same sensory format presented, has large capacity, but lasts only for a very brief time, (2) working memory which holds information in an organized format, has limited capacity, and lasts for a short period of time, and (3) long-term memory that holds information in an organized format, has large capacity, and lasts for long periods of time [102].
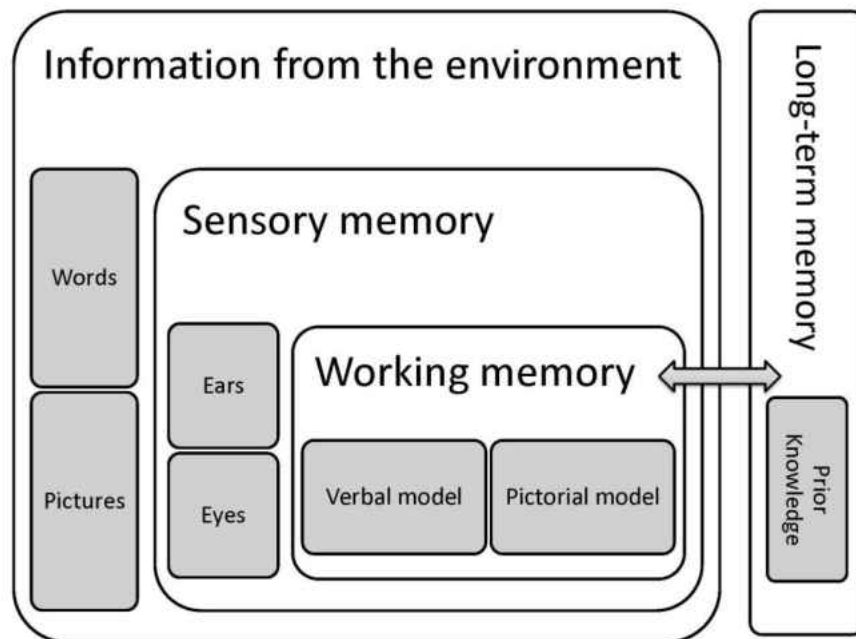
Figure 2.1: Cognitive structure and information processing model.

The integration of information in different modes is commonly termed multimedia. If relevant pieces of information are linked, the resulting direct connection of such information is referred to as hypermedia. The combination of multimedia and hypermedia resulted in the invention of the internet which evolved a technology that closely resembled human long-term memory [103]. Considering the long-term memory, one provocative insight by psychologist Herbert Simon is that long-term memory is a fully cross-referenced encyclopedia which simply means that everything is interconnected [104]. Therefore, some of the features of the long-term memory resemble information presented in electronic form by computers and on the internet.

Researchers have found out that people better recall concrete information compared to abstract information. In learning sciences, this concept is referred to as the concreteness effect [101]. Psychologist Allan Paivio explained how the concreteness effect supports the idea that people have separate information channels for words and pictures [105]. For this reason, he proposed the dual coding theory. This theory recognizes language and mental imagery as two dominant forms of knowledge used by the mind. According to Paivio's dual coding theory, people learn better when they use two codes (rather than one) to represent incoming information. A similar concept known as the picture superiority effect also states that an item is better remembered if it is presented as a picture rather than a word [101]. In addition to these and many other convincing arguments in favor of using multimedia and imagery information in learning, researchers also realized that the missing link in the diagram presented in Figure 2.1 was "motivation". A student's motivation to learn is reflected in the amount of effort he or she puts on understanding the course material while being engaged in the appropriate cognitive and active processes of learning and understanding [106]. Table 2.1 shows five conceptions of how motivation works for students [107].

Table 2.1: Five conceptions of how motivation works.

| Basics | Description |
|---|---|
| Interest | Personal interest would motivate students to work harder to learn a concept. |
| Beliefs | Students would work hard to learn when they realize their hard work will pay off. |
| Attributions | Students work harder when they attribute their successes and failures to effort. |
| Goals | Students work harder when they have a personal goal. |
| Partnership | Students work harder when they feel working together with other students and instructor. |

Moreover, according to several learning theories, "metacognition" is also a critical factor in the learning process, which refers to the learner's knowledge of how to improve his or her learning [108]. This goal is achieved when learners know the best way they learn (awareness) and how they can control their learning (control) [109]. Hence, in this research, first, a pre-survey test from 241 undergraduate students was taken to gain a better understanding of students' awareness about their learning mechanism and obtain feedback about the potential of using technology and mobile devices as a learning tool in the classroom. The results which were discussed in detail in Chapter 1 showed that students perceive visual information and technologies as an effective learning aid that can potentially supplement traditional text-reading methods. Although such visual aids could also be provided through the use of computer presentations or overhead slides, the author hypothesized that the motivation aspects (as described in Table 2.1) could not be properly supported by simply adding visual presentations to course materials. The aforementioned learning theories combined with the critical role of motivation in learning was the

underlying reason behind selecting and using mobile AR as an innovative approach to combine traditional and technology-based course delivery techniques into a single platform. As will be described in detail in Chapters 4 and 5, the developed tool provided a unique opportunity for students to use both their verbal and visual capabilities to learn better and more, as well as created a collaborative and interactive technology-based learning environment in the classroom by allowing discussions and teamwork. The developed approach thus supported and reinforced all previously mentioned principles namely active processing, and different motivation concepts such as interest and partnership.

## 2.5 Learning Theories and Constructivism

Constructivism is one of the fundamental learning sciences which focuses on two critical aspects of learning: social and cultural [110]. The two central ideas of constructivist theories are (1) learners are active in constructing their own knowledge, and (2) social interactions are important in the knowledge construction process [111].

Vygotsky [112] emphasized that social interaction coupled with cultural tools and activity shape individual development and learning. In psychological (cognitive) constructivism, learning means individually possessing knowledge, but in social constructivism, learning means belonging to a group and participating in the social construction of knowledge [113]. He combined both psychological and social constructivism in his theory. Similarly, Windschitl and Sahl [114] indicated that one way

of integrating individual and social constructivism is to think of knowledge as both individually constructed and socially mediated. The prospect of combining individual and social constructivism also served as the backbone of this research. In particular, using the developed AR applications, students not only were able to work interactively in groups and under the instructor's supervision in class, but also could use the tool individually at home to review and reinforce the class materials.

Psychologists who emphasized on the social construction of knowledge and situated learning have affirmed Vygotsky's notion that learning is inherently social and embedded in a particular cultural setting [115]. Situated learning emphasizes that learning in the real world is different from studying in school. Situated learning is often described as "enculturation" or adopting the norms, behaviors, skills, beliefs, language, and attitudes of a particular community [116]. In this research, the community is in fact "other students in the same class" and in other words, a group of people that has particular ways of thinking and doing. The learning takes place by encouraging students to participate more in the practices and using the tools [113, 117, 118]. However, in the basic level, situated learning suggests that much of what is learned is specific to the situation in which it is learned [119]. Hence, collecting the latest appropriate information and using it in the classroom via new technology-based devices were another supportive idea of designing the developed AR tools in this research.

Researchers also cited collaboration as an effective learning method since collaborative work and social experience not only do help students adjust to others at an emotional

level, but also serve to clarify a person's thinking and ultimately help him become more coherent and logical [120]. Studies also proposed that an essential feature of learning is that it creates the "zone of proximal development" where a variety of internal developmental processes are established and operate when students are interacting with people in their environment and in cooperation with their peers. Once these processes are internalized, they become part of the students' independent development achievement [112]. Equally important, is the proper transfer of knowledge to the students so that they can benefit from what they learn and retain their skills for future applications in potentially new situations [121]. Knowledge transfer across contexts is especially difficult when a subject is taught only in a single context rather than in multiple contexts [122]. It has been claimed that when a subject is taught in multiple contexts and includes examples that demonstrate wide application of what is being taught, people are more likely to abstract the relevant features of concepts and develop a flexible representation of knowledge [123]. Therefore, designing and implementing an application to support multiple contexts in one course can potentially have a high impact on the learning process. Therefore, the author also incorporated "context-awareness" into the developed AR tools in this research.

# CHAPTER 3: MOBILE AUGMENTED REALITY (AR) FRAMEWORK

## 3.1  Overview

Augmented Reality (AR) is an advanced visualization technology which is used to supplement real world observations by allowing the user to view a real environment augmented with computer generated 3-dimensional (3D) information [71]. The introduction of AR to the architecture, engineering, and construction (AEC) industry has recently resulted in significant advantages through visualizing and more effectively communicating complicated field tasks and project operations [124]. According to Azuma, the core requirements of a functional and reliable AR system include the ability to (1) follow the observer's viewpoint with a tracking system, (2) superimpose virtual content over the real world views with proper scale and in correct location and orientation, and (3) combine real and computer-generated virtual contents in a seamless manner [71]. In addition to these basic features, the ability to continuously update and display information that is relevant to the user's context is critical in almost all engineering and scientific applications that deal with data-intensive tasks [125].

In Chapter 2, the current state of AR technology integration into construction and civil engineering education was presented and the potential resulting pedagogical impacts were reviewed. It has been discussed that AR can enhance the visual, aural, and tactile senses with virtual or naturally invisible information superimposed on top of the real

world [126, 127]. AR also enables the preservation of the real environment that provides a reference frame for user's actions, thus making a visual and haptic interface which changes the human-computer interaction to a more natural phenomenon [71]. As previously stated, the creation of AR environments requires designing virtual representations and displaying them over the views of the real world. Compared to virtual reality (VR), the model engineering task (the process of creating, filtering, rendering, and displaying the virtual content) in AR is less computationally intensive for it is not necessary to create and render detailed 3D models of objects that are part of and already represented in the real world [128]. Moreover, in mobile AR interfaces that can be launched on smartphones and tablet devices, users can interact with virtual objects without having to wear expensive and bulky equipment such as head-mounted displays (HMDs) [82] while the real world is conveniently captured by the built-in camera of the device. This allows users to have a portable and ubiquitous AR tool in their hands that can be deployed on-demand. While AR simulation and visualization provide potentially transformative benefits, they also present unique technological, managerial, and cognitive challenges to the learning process [129]. For instance, the small size of the screen (in smartphones) and image distortion (considering the limitations of mobile processors) are to certain extents considered as disadvantages of mobile AR applications.

Unlike virtual environments, users in AR are able to naturally communicate with one another which can enhance and support the collaboration aspects associated with learning. Previous studies summarized the main potentials of AR applications as

improved spatial and practical skills, conceptual understanding, and inquiry-based activities [130]. Scientists have shown that by allowing users to physically move in the real world (as the spatial context) while interacting with virtual objects, mobile AR applications can create opportunities for better learning with long-lasting impact [129]. Conducting hands-on experiments facilitates more effective learning that can be directly applied to the real world. Therefore, if properly used, AR not only does combine the real world experience with the learning process, but it can also create interactive and collaborative educational scenarios which motivate students to communicate with each other, focus on the goal of learning the presented contents, and further collaborate and participate in group discussions even outside the classroom. As stated in previous Chapters, a thorough study of these and several other recent work aimed at evaluating the educational impact of AR motivated the author to pursue an inclusive approach to use AR visual simulation in engineering education. In the presented research, and for proof-of-concept experiments and validation scenarios, construction and civil engineering was used as a test bed. However, in the future, the findings of this project are sought to be generalized to and useful in broader areas of science, technology, engineering, and mathematic (STEM) education.

## 3.2  Mobile Devices and Technological Learning Abilities

According to a 2013 survey conducted in Project Tomorrow, students overwhelmingly have access to personal 3G- or 4G-enabled mobile devices. In the same research, students mentioned the positive impact of mobile devices in their daily tasks and in transforming

their learning experience. The results indicated that 60% of students were using mobile devices for anytime research, 43% for educational games, and 40% for collaboration with their peers [12]. Existing instructional information delivery techniques involve not only the use of written material such as textbooks and articles, but also the ability to manipulate and interpret multimedia contents such as images, videos, sounds, and graphics. As such, the learning experience to a large extent has turned into an active process in which students can participate and take meaningful charge of different aspects of classroom activities.

Recently, the importance of fostering meaningful learning has been elaborated upon under the general topic of situated and active learning [116, 131, 132]. Evidently and to support the prospect of active learning, mobile technologies that enable the ubiquitous and customized delivery of information can enhance the ability to learn instructional materials while allowing students to better understand new, multiple-media genres. Furthermore, with many handheld devices, it is possible to overlay virtual data on real world views and thereby connect a virtual world to real life situations [133]. In addition, the large capacity of most mobile devices to collect, store, and process (real world or simulated) data is one of the other great features that makes them well-suited for supporting a variety of learning activities in different contexts and environments. Other advantages of using mobile devices particularly for educational purposes are their portability, social interactivity, connectivity, and individuality [134]. Most mobile

devices also support the latest visualization techniques such as AR for use either in individual settings or in collaborative shared spaces.

Considering these factors, mobile AR was used in this research as a promising pedagogical tool to facilitate learning in interactive environments, enhance student engagement, and ultimately transform traditional instructional techniques. The author designed a context-aware mobile AR platform and used it in different undergraduate construction and civil engineering courses to assess its pedagogical potentials in engineering education. In doing so, the goal was to make a transition from content- and teacher-centered instruction towards a more student-centered strategy that enables personalized and self-directed learning [135]. Other overarching pedagogical goals of this work were to help students gain more informative longer-lasting visual and conceptual knowledge, as well as to assist instructors in obtaining a better understanding of how students perceive and interact with classroom technology. In the longer term, the findings of this research can contribute to other STEM disciplines through expanding the application domain of the designed pedagogical methodology and educational tools to other engineering and scientific fields.

## 3.3 Pedagogical System Design Principles

Educational researchers and practitioners have long been advocating the notion of 1:1 computing, which refers to equipping students with personal mobile devices and enabling 24/7 access so that the devices can mediate their classroom as well as out-of-classroom

learning [136]. Various studies have provided designs for supporting student inquiry-based learning using mobile technologies [137-139]. In order to develop an educational application, technological, domain specific and pedagogical aspects of the design have to be carefully examined. Context-aware systems featuring contextual data, engaging learning experiences, and improved learning effects have been applied to different learning activities [140]. Dey [141] defined context as contextual information about an entity, which may be a person, a place, or a physical object. This information is considered relevant to the interaction between a user and an application. In this study, the context-aware mobile AR platform was created using an open-source, third-party, web-based programming environment [142]. Several researchers have listed key principles of an effective educational system design, as follows [143]:

1. Interaction

2. Empowerment

3. Awareness

4. Flexibility

5. Accessibility

6. Immediacy

7. Minimalism

In order to have the best design, these principles should be instantiated through a participatory process with the teacher and tested in the classroom. Therefore, the author incorporated all these principles in the developed pedagogical mobile AR applications in

this research. In particular, using the context-aware mobile AR application to display additional visual information coupled with the teacher's knowledge of the subject matter provides empowerment (item 2) and awareness (item 3). Moreover, allowing students to use the tools individually or in collaborative group settings provides interaction (item 1) and flexibility (item 4) in the design by enabling students and teachers to work together to cope with varying levels of knowledge within a group or between the groups. However, recent studies indicated that one of the key considerations for designing AR experiments is finding the best ratio of role overlap in a teamwork task. According to Klopfer et al [144], too much overlap between the roles could remove the positive interdependence and individual accountability and too little overlap does not give the students enough common ground to discuss the issues.

With regard to accessibility (item 5) and immediacy (item 6), learners can immediately access audio and video learning materials anywhere and at any time and receive immediate response from the AR tool as long as their handheld devices are connected to internet. Finally, minimalism (item 7) was maintained in both the visualization features of the interface and the number of available functionalities. Therefore, this study integrated teachers, textbooks, handheld AR, laboratory experiments and information technology to construct a learning environment in support of all seven design parameters listed above.

## 3.4  System Design

In this study, the author designed, implemented, and assessed an AR-based pedagogical tool to better engage students in the learning process and to create an environment in which students are motivated to learn abstract construction and civil engineering topics. For this purpose, two separate sets of experiments were designed and conducted to test the effectiveness of AR instructions: (1) an AR pop-up book, and (2) a building design and assembly project. Detailed description of these experiments and their findings will be presented in Chapters 4 and 5.

A key component of any AR application is accurate registration of virtual contents inside the real world space. Registration guarantees that real and virtual objects are always aligned inside the user's viewing frustum [145]. There are two registration techniques that are commonly employed in AR: marker-less, and marker-based. In this research, the marker-based registration technique was used. In particular, students should first use their handheld devices to scan a quick response (QR) code. The QR code in essence, helps identify the proper mapping between virtual information and the real world. As shown in Figure 3.1, users first scan a QR code using the built-in camera of their web-enabled handheld devices to access the correct information channel. This QR code can be printed on a piece of paper and carried easily by the user to different locations. Once the QR code is scanned and identified, either subsequent scanning of a predefined AR marker (a.k.a. tracking image) or moving the mobile device in the direction of a predefined point of

interest in the real world will result in a specific virtual content overlaid on top of the real world background.
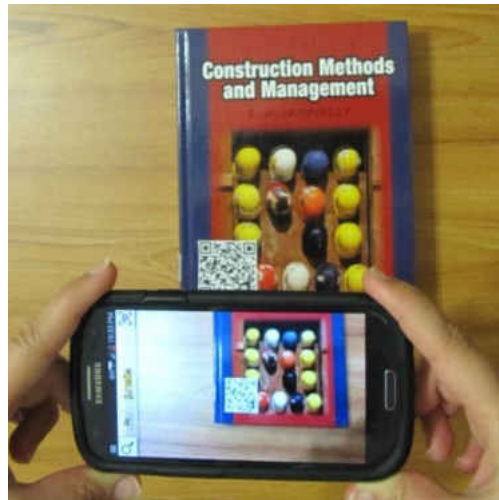


Figure 3.1: Scanning the QR code using handheld devices.

The AR applications used in this research was designed based on Junaio, an open-source web-based AR experience language (AREL) programming environment [146]. Junaio offers a free, web-based application programming interface (API) which enables users to access the AREL content and create various AR applications. The AREL package includes three different components: (1) the static extensible markup language (XML) to define all the content and linkages, (2) the Javascript logic to define dynamic parts such as user interactions, and (3) the content itself which includes 3D objects, images, and other multimedia files. The source of the AREL is identified by a channel content uniform resource locator (URL). This URL delivers the AREL XML through the mobile application. Using this process, when a user scans a QR code corresponding to a specific channel, a hypertext transfer protocol (HTTP) request will be sent to the server. The

server will then forward the request to the channel content URL and responds to the request with either a static or dynamic XML. This XML will then be forwarded to the user and enables the user to receive desired content such as 3D models, images, movies, or other multimedia. The sequence diagram of the user query process is shown in Figure 3.2.
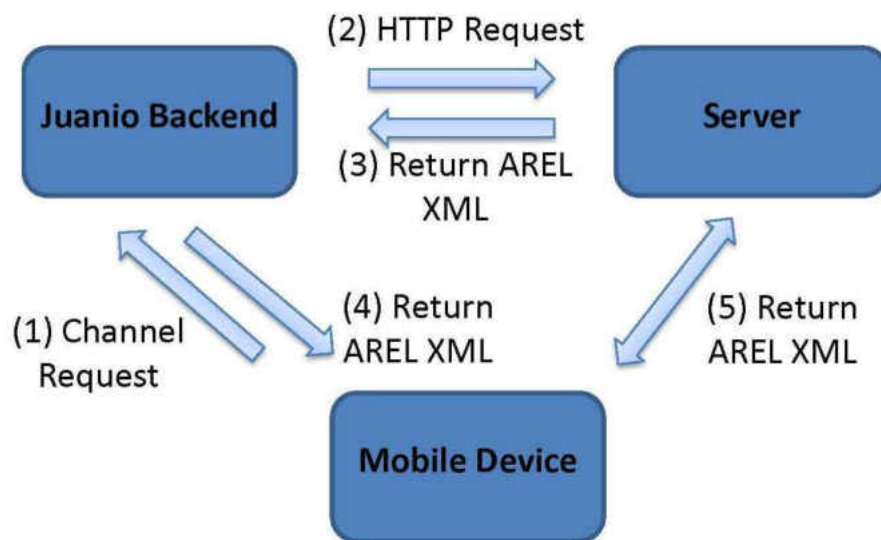
Figure 3.2: Sequence diagram of the user query process in Junaio.

Each channel has its unique channel identification (ID). When the application accesses a channel, it passes the channel ID to the server, and then forwards the request to the channel's content URL. The content server URL (a.k.a. callback URL) is the HTTP address of where the channel XML is created. For AREL channels that deliver static XML, the callback URL will be a simple link to an XML file. Static XML files considered as the simplest and fastest channels since the server should only provide the file without interpreting any server code. However, the channel logic is implemented in

Javascript. On the other hand, in dynamic channels that return dynamic XML based on the user input, the resulting XML has to be created dynamically. The visual descriptions of static and dynamic channels are presented in Figure 3.3. In dynamic channels, there can be a database that contains the required objects. Hence, as shown in Figure 3.3, based on the input, the Hypertext Preprocessor (PHP) code could perform a database query and return all point of interest (POIs) close to the user's position. Using the AREL PHP helper provided by Junaio, the developed PHP script can create AREL XML and return it to the user.
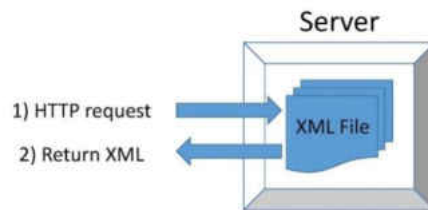


(a)
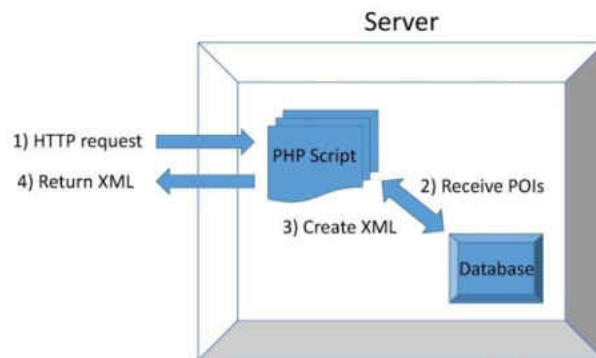


(b)

Figure 3.3: Structure of (a) static channels, and (b) dynamic channels in Junaio.

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A very important and convenient feature of the developed application is that all computer-generated information (2D/3D models, video and sound files, images) are stored and updated on a host server maintained by the application developers. End users (i.e. students) do not need to download large volumes of information onto their mobile devices. Instead, they simply download and install a small application on their devices that will, in turn, communicate with the online data server and pull necessary information in real time. Given that students and instructors have easy access to Wi-Fi internet on campus and that 3G-4G mobile internet is becoming more widespread, this approach significantly reduces the processing time while giving application developers the flexibility to update or modify parts of the application from a remote server without having to physically access and run updates on each and every mobile device used by the students.

Through these processes, end-user and server communicate over a wireless internet (Wi-Fi or 3G-4G mobile connection) and the developer exchanges data with the server over HTTP. All data processing and transfer methods used to develop the mobile AR framework as described earlier, are programmed in the PHP language. This allows computer-generated information about different locations or objects to be linked via their corresponding channels. A channel is an AREL application that is registered on the server. It is in fact, a link to the remote server where the content is stored. Therefore, the Junaio backend is basically a distribution platform for the developed AREL application. Junaio employs two different channel types: location-based channels, and image-based

channels. In this research, both channel types were used in designing educational mobile AR applications. In the following Subsections, these two channel types are described in more detail.

### 3.4.1    *Location-Based Channels*

Location-Based channels show POIs in the users' surroundings. When location-based channels are used, users can view the real world through the built-in camera of their mobile devices while the application overlays virtual information about POIs in the user's surrounding as soon as they are detected. Users can hold their phones up and look around to see virtual objects floating over different POIs. From a more technical point of view, location-based channels load a global positioning system (GPS) tracking configuration which use GPS, compass, accelerometer and gyroscope of the handheld device to render visual information on the user's real world view.

Figure 3.4 shows the steps involved in the information delivery process from the moment the user scans a QR code until context-aware information is displayed through the display of his or her mobile device. In this Figure, the tracking device is the same as the displaying device, both being the user's mobile unit [142, 146, 147].
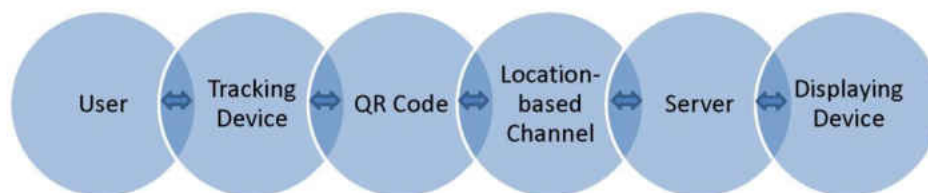
Figure 3.4: Process flow in a location-based channel.

### 3.4.2   Image-Based Channels (GLUE)

Image-based channels enable developers to link certain virtual content (e.g., video, audio, images, or simulated animations) to a marker (a.k.a. tracking image). The user should first scan the specific QR code to access the corresponding channel. Then, as soon as the marker is visible through the input device (e.g. camera, HMD), virtual information assigned to that marker is overlaid on top of the user's view.

Figure 3.5 shows a complete sequence diagram of how image-based channels work from the starting point that the user uses his/her mobile device to scan a QR code towards the very last stage that the device receive the visual information and display it to the observer's mobile screen.
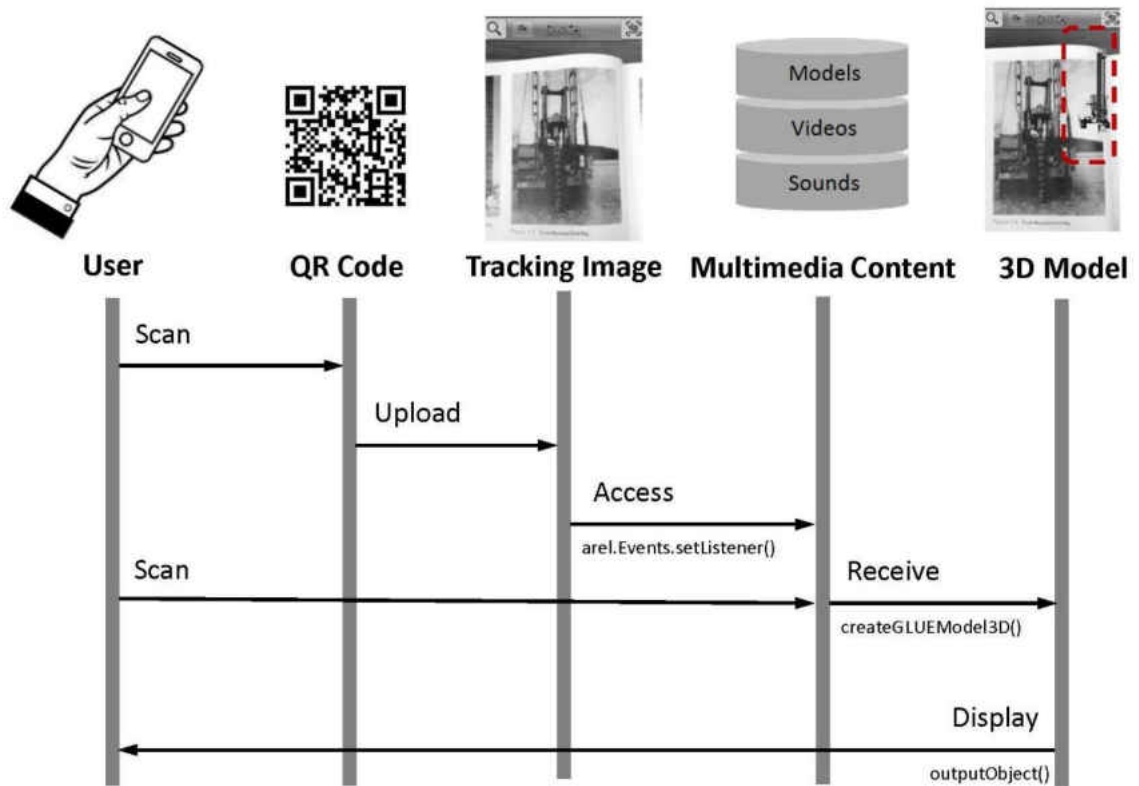
Figure 3.5: Sequence diagram of image-based channels.

As described in previous Chapters, a major gap in knowledge that still remains in using instructional technology in large scales is the lack of proper and systematic assessment methodologies to evaluate the short and long term benefits of such advanced technologies to the performance of students and trainees. Therefore, this research was an attempt to not only develop and implement mobile AR applications using the design principles described in this Chapter, but also to conduct comprehensive performance assessments of the pedagogical impact of using such tools in classroom settings and present the results in a meaningful format to facilitate future research. For this purpose, two separate sets of

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experiments with well-defined goals were designed and carried out throughout the course

of this research. In Chapters 4 and 5 detailed descriptions of the developed mobile AR

tools in Junaio, the methodology and steps that were followed in each experiment, and

the assessment and students' feedback results will be presented.

# CHAPTER 4: EXPERIMENT 1: ENHANCED TRAINING USING CONTEXT-AWARE MOBILE AUGMENTED REALITY (AR)

## 4.1 Overview

One of the main challenges in deploying a new educational technology in classroom is to ascertain that the resulting positive impact of using such technology on student learning is long-lasting. A technology-based pedagogical tool that keeps students engaged and interested in classroom activities but fails to address issues such as long-term retention of information will most likely have limited impact on the overall learning process. To this end, an important issue is to use technology in a proper way through first establishing clear educational objectives and then, assessing whether the new educational technology meets or exceeds these objectives both in short-term and long-term [148].

As discussed in previous Chapters, during the preliminary studies conducted as part of this research, it was observed that while students had a very good knowledge of new visualization technologies such as virtual reality (VR) and augmented reality (AR), they were still not able to fully take advantage of them in their learning process [149]. Given that VR and AR technologies have become more accessible and easier to use, the author was motivated to develop, implement, and test the potential of such technologies in real classroom settings.

In Chapters 2 and 3, different visualization technologies, and their similarities and differences were studied and it was concluded that mobile AR could bring about added

benefits to student learning. Therefore, several hands-on experiments were designed and implemented using mobile AR to provide students with an opportunity for situated learning and constructivism, all in an effort to resemble real world scenarios in the classroom [116]. As described in Chapter 3, AR can help augment the learning experience with real world scenarios and thus create an interactive and motivating learning experience resulting in more participation and group discussions even outside of the classroom environments.

Considering these facts, the first set of experiments conducted in this research aimed at designing, implementing, testing, and assessing (in short-term and long-term) a new technology-based pedagogical methodology based on mobile AR visualization to support the prospect of a more engaging learning experiment for construction and civil engineering students and instructors. In particular, a context-aware mobile AR tool (CAM-ART) was designed and tested in an undergraduate course at the University of Central Florida (UCF). The goal of this experiment was to bring technology into a regular classroom by enhancing the contents of ordinary course textbooks. Therefore, not only the instructor and textbook were not eliminated from the learning procedure, but also they were supplemented with a new technology-based pedagogical tool that enhanced the leaning quality. The overall experimental design of the developed framework is illustrated in Figure 4.1.
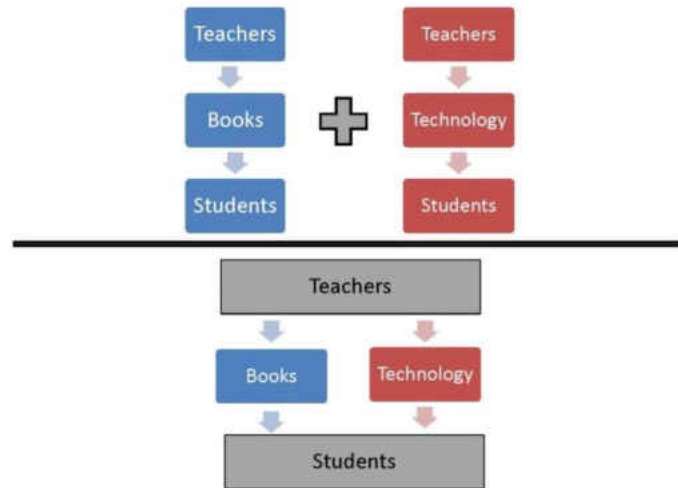
Figure 4.1: Experimental design used to combine traditional and technology-based learning methods.

## 4.2 Methodology

The mobile AR tool designed for this experiment, CAM-ART, can be launched on mobile devices running on Android or iOS operating systems, and provides students with a means to see and interact with the contents of their textbooks. Since a mobile device provides the user with both input (via its built-in camera) and output (via its display) capabilities, the user does not have to wear extra peripheral devices such as AR goggles or head-mounted displays (HMDs) and thus, is less likely to be distracted during the learning experiment. The tangible product of this experiment is an AR pop-up book which in essence, is an enhanced version of a traditional textbook by providing contextual linkages to multimedia and 3D graphics that can be displayed on-demand to the reader. Students are able to use their books without the need to carry any additional

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devices or hardware. However, as shown in Figure 4.2, when looked at through a mobile

device (e.g. smartphone, tablet), 3D graphics (models, animations) and multimedia (e.g.

video, sound) corresponding to the content of each page is displayed to the student.
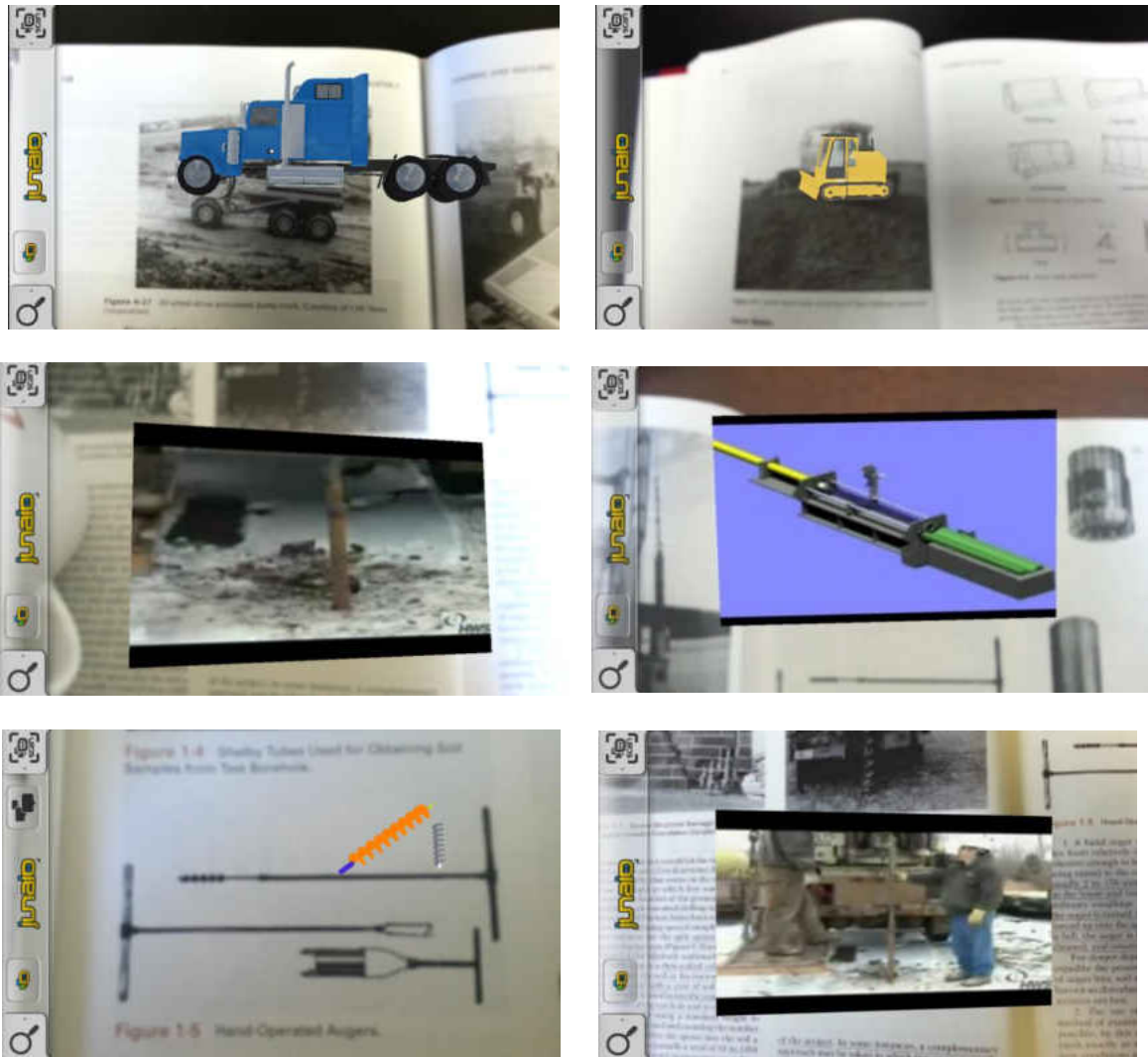


Figure 4.2: Computer-generated virtual content is delivered to students via their mobile
devices as they hover over different images of the textbook.

Using mobile AR tools such as CAM-ART can be the first step in immersing students in their course topics. Billinghurst et al. [89] showed that using an AR pop-up book results in classroom collaboration since it can bring three levels of interaction together: using a physical object, using an AR object, and immersing in a virtual space.

In this research, Junaio image-based channels were used to create the CAM-ART interface. A sample chapter from a construction methods and management textbook [150] was enhanced by augmenting different types of virtual information (e.g. 3D models, videos, sound clips, and 2D images) on existing figures, tables, and diagrams of the book (used as AR tracking images). Prior to studying the contents of their textbooks, each student uses the built-in camera of his or her web-enabled handheld device to scan a quick response (QR) code. Then, as students move their handheld devices over the images of the book, 3D computer generated and other multimedia (e.g. videos, sounds, images) appear on top of the textbook images. More information about the details of the supporting Hypertext Preprocessor (PHP) programming in the image-based channel can be found in Appendix B. Figure 4.3 shows snapshots of single-user and multiple-user feasibility experiments conducted using CAM-ART.

(a) Students use the built-in camera of their mobile devices to scan a QR code.
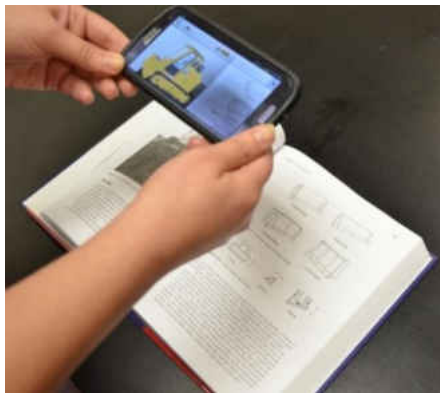


(b) Single user viewing virtual contents overlaid on a book page.



(c) Two users simultaneously viewing virtual contents overlaid on two different pages.

Figure 4.3: Students scan the QR code and computer-generated virtual content is superimposed and displayed on top of printed images of the textbook.

This process enables students to collaboratively work with their peers to discuss the delivered information. The ability to use multiple devices at the same time in a group enhances participation and encourages interaction between members of that group. It also enables teachers to form teams of arbitrary number of students, and easily implement the tool in classroom by asking students to use their own mobile devices at no additional cost (see Figure 4.4).



Figure 4.4: Students working in groups while using CAM-ART to access data relevant to the lecture topics.

As mentioned in Chapter 3, the lack of a proper and systematic assessment methodology to evaluate the short- and long-term benefits of advanced educational technologies to the performance of students and trainees is still a major problem. Therefore, this research also tried to fill in this gap by conducting a comprehensive performance assessment of the AR pedagogical tool using student performance data collected in real classroom settings, and presenting the results in a meaningful format to facilitate future research in this area. More information about the designed experiments and the results are explained in detail in following Sections.

## 4.3 Assessment Techniques

An important step in this experiment was to test the methodology in a real classroom and allowing students to experience with CAM-ART, observing and collecting their performance data, and evaluating if any improvement to the learning process was evident. One of the challenges in educational research is generating assessment exercises that yield enough evidence to draw valid conclusions and interpretations about student learning [151]. In order to address this challenge, a two-stage implementation procedure was used in this experiment. The first stage included single classroom testing of CAM-ART, while the second step will include a collaborative effort among several universities as part of future directions of this research, and will assess the benefits of the developed learning tool in multiple courses using larger and more diverse student populations.

In this experiment, CAM-ART was used in an undergraduate course titled "CCE4004 – Construction Methods" offered every spring semester by the Department of Civil, Environmental, and Construction Engineering at UCF. In particular, two "mystery" lectures were included in the course calendar and three different assessment steps were deployed. The course was offered in spring 2013 and had a total enrollment of 16 students. Figure 4.5 shows student gender information. Table 4.1 shows the calendar of the experiment.
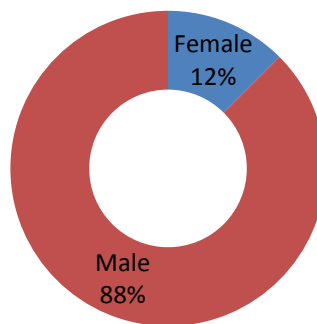


Figure 4.5: Gender breakdown of 16 students participated in the first experiment.

Table 4.1: Calendar of the first experiment.

| Task | Date |
|---|---|
| Pre-survey Questionnaire | Tuesday, March 26, 2013 |
| Group A Mystery Lecture (8 students) – Pre-lecture test at the beginning of the lecture, deliver conventional lecture, post-lecture test at the end of the class | Tuesday, April 2, 2013 |
| Group B Mystery Lecture (8 students) – Pre-lecture test at the beginning of the lecture, deliver lecture using the newly developed pedagogical tool, post-lecture test at the end of the class | Thursday, April 4, 2013 |
| End of Semester Test – Give the same test simultaneously to all 16 students without their prior knowledge in about one month after the mystery lectures (at the final exam) | Tuesday, April 30, 2013 |

In this stage, students were randomly divided into two groups (A and B) each consisting of 8 people. Group A was used as the control group and asked to attend the first mystery lecture, and group B was used as the test group and asked to attend the second mystery lecture. The two lectures were identical in terms of learning objectives and learning material, and differed only in that one allowed students to used CAM-ART, whereas the other did not, as shown in Figure 4.6. Students in both groups were not told ahead of time what to expect. This was essential to make sure that they came to class with minimum positive or negative bias towards the lecture material and delivery techniques. However, following a procedure discussed in Chapter 1, they were all given a pre-survey questionnaire about one week prior to mystery lectures so that basic personal information (e.g. gender, program of study) as well as information about their level of familiarity with some technical terms (e.g. VR, AR) and possession of certain tools (e.g. computers,

tablets, and smartphones) could be collected. Each student was also assigned an ID number and the collected information was used to properly assign each student to either group.



Group A – conventional lecture.



Group B – AR-enhanced lecture.

Figure 4.6: Two mystery lectures were conducted during the first experiment.

The topic of the lecture was selected to be "construction site investigation". Group A (control group) only attended the first mystery lecture were material was delivered using conventional instruction methods including PowerPoint slides, lecture notes, and textbook. Group B (test group), on the other hand, attended the second mystery lecture

were the same topic was delivered using CAM-ART. Group B was further divided into teams of 2 people (a total of four teams) and each team was allowed to work collaboratively and interact with the designed features of CAM-ART on their own tablets or smartphones, as shown in Figure 4.7.





Figure 4.7: Students working collaboratively in groups of two people using multiple devices.

As previously stated in Subsection 4.1, an important implementation issue in this experiment was to establish appropriate techniques and guidelines to effectively assess the benefits of the new tool and analyze its impacts on the learning process. For this purpose, and considering different aspects and limitations of available assessment techniques, nine different classroom assessment techniques (CATs) were selected from a set of fifty techniques as introduced by Angelo and Cross [152], and used to systematically evaluate the pedagogical value of CAM-ART and check if it made any meaningful difference when used in an actual classroom. Using these nine CATs, three questionnaires were created and distributed according to the calendar of Table 4.1. The questionnaire is presented in Appendix C. A brief description of the selected CATs and how the questionnaires were designed is presented in the following Subsections.

### 4.3.1 Background Knowledge Probe

This technique is normally used to collect more feedback on students' background knowledge about a certain topic which will be presented to the students shortly after. In this technique, instructors ask students simple and short questions to obtain information about their prior knowledge before they start teaching the new topic. In this experiment, this CAT was used to create a pre-survey questionnaire and collect data that gave more insight as to how students perceived the idea of bringing technology into the classroom, as well as whether they felt comfortable and were willing to use their mobile devices in classroom while listening to the lecture.

In addition, this CAT can be used as a pre- and post- assessment tool. As such, it was used in this experiment to study the student learning process by creating a separate questionnaire that included questions about the most important topics and discussions presented during each mystery lecture. Students were asked to answer these questions both before and immediately after the lecture. This was critical as it helped investigate how much and how well they learned the lecture materials. Moreover, as listed in the calendar of Table 4.1, to assess students' long term learning and information retention, they were asked (without prior knowledge) the exact same questions about one month after they attended the mystery lectures.

### 4.3.2 Memory Matrix

This CAT uses a rectangular table (i.e. matrix) with two rows and columns. Students fill in the blanks by taking into account the mutual relationships between different rows and columns. The purpose of this method is to check students' organizing ability and help teachers assess if the provided information has been transferred correctly and in an organized manner. This CAT is especially recommended in courses with high informational content and is often used after lectures with categorized information. A sample question designed with this method and used in this experiment is shown in Table 4.2. This question was used in the pre-lecture, post-lecture, and final test. The corresponding question to this memory matrix was:

*"Which of the four following statements are advantages of test pits and which are the*

*disadvantages? Put the corresponding numbers in table provided below."*

Table 4.2: A sample question designed for the memory matrix CAT.

| | |
|---|---|
| 1. *Examine the layers of earth exactly as they exist.*<br>2. *Expensive*<br>3. *The depth to which examination can be carried out is limited.*<br>4. *Soil moisture conditions are evident* | |
| Advantages | Disadvantages |
| | |
| | |

The memory matrix helps instructors check not only if information can be recalled by students but also if students can distinguish between different facts and organize their knowledge. On the other hand, "visual learner" students can learn better using this technique since all delivered information is categorized in a relational format.

### 4.3.3 Categorizing Grid

This CAT is also used for categorizing information and sorting objects corresponding to their types. In this technique, students are provided with a scrambled list of information such as words, terms, and images, and are asked to put each piece of information into its correct category. This CAT is to some extent similar to the memory matrix and was used in this experiment in pre-lecture, post-lecture, and final test questions to check students' ability in sorting lecture information and to determine how well students learned and could identify course materials.

Using this CAT provides students with an opportunity to rethink about the new materials and recall them when necessary. This method is also useful for introductory classes with all sizes. In most situations, the results obtained from implementing this technique reveal which parts of the delivered course material are more likely to be misunderstood or left blank by students. This will ultimately help instructors put more emphasis on those parts.

### 4.3.4   Defining Features Matrix

This CAT requires students to define the presence or absence of a specific feature in a particular category and can therefore, assess students' ability to categorize their knowledge into different features provided by the instructor. Using this CAT, instructors can check if students are able to distinguish between several concepts. Moreover, similar to the previous technique, it can highlight common mistakes made by students, guide instructors to work more on those parts, and also help find the most effective elements of the lecture in which students showed higher interest.

However, one of the cons common among all of the four CATs discussed so far is that sometimes, not all the information can be necessarily put into an organized and categorized format. Therefore, the author went beyond course-related CATs and used several other techniques to enhance the assessment procedure and check other aspects of CAM-ART as far as student's learning experience was concerned. The following techniques describe these assessment methods in more detail.

### 4.3.5 *Approximate Analogies*

This CAT assesses synthesis and creative thinking skills by asking students to complete the second half of a sentence in which the first half is already given. By doing so, instructors will be able to determine whether students understood and can identify potential relations between two statements (or concepts). Additionally, the results of this CAT demonstrate if students are skilled enough to effectively and creatively relate two concepts to each other as well as memorize new related topics. One of the examples of this type of question that was included in pre-lecture, post-lecture, and final tests is shown below:

*"Drill bit is to rotary drill as …………………… is to diamond drill."*

- a) *Diamond-studded bit*
- b) *Chisel shaped cutting edge*
- c) *Control means*
- d) *Drill bit*

One of the other advantages of this method is that it can be used in any discipline that requires students to realize relationships and classify information. This method will have much more effect if students work in small and collaborative groups (as was the case in this experiment) and share their ideas and different opinions about a particular topic.

### 4.3.6 Course-Related Self -Confidence Surveys

In this CAT, students gain confidence in their ability to handle specific contexts related to the course topic. In this experiment, students were asked to answer questions about their confidence in using the new AR technology in classroom and working with it to learn, as well as applying the information they learned using this technology. Using this CAT, instructors can assess if students have learned relevant skills and materials. Knowing students' self-confidence about a topic and the effective factors in their motivation are basic agents that instructors can learn by using this method. Finally, obtained results will help instructors work much better in providing students with useful information and productive assignments. Once students are aware of their confidence in the topic, controlling and improving their performance will be a much easier task.

One of the advantages of this CAT is that it is useful for courses requiring students to get familiar with new skills or skills that they once failed to learn. This method can also be used both before and after the lecture, similar to how it was used in this project, to study students' progress in learning a particular course topic. Breaking down the class into small groups and asking the members of each group to work together and help each other will support the prospect of gaining self-confidence in the topic. Thus, the author selected this CAT as one of the assessment methods.

### 4.3.7 Punctuated Lectures

This CAT is implemented in five steps: listen, stop, reflect, write, and give feedback. Listening to the lecture is the first step. After that, the instructor stops talking, lets

students to discuss their opinions, and then answer the feedback questionnaire. This technique is used especially when immediate feedback is needed. It targets students' attention to the lecture and their learning process. In this experiment, this method was used in both mystery lectures given to Groups A and B in order to guide students during the conventional presentation. Doing so enabled the author to compare Group A (control group) with Group B (test group), and identify both distracting and effective factors in each lecture by dedicating more time for realization and discussing the issues in groups for Group B.

Moreover, the author used this CAT to assess how well students could concentrate particularly since some students were visual learners and could not fully concentrate on listening. It was concluded that when simultaneous listening and watching was an option, especially in 3D contents, the concentration rate increased. In addition, this method can be used even in classes that cover difficult concepts or complex procedures to automatically eliminate the likelihood of misunderstanding. However, as stabilizing the topic is still a challenging task, answering the same survey questions after a long time (one month, in this experiment) was also deemed a good strategy to obtain a more precise assessment output.

### 4.3.8  Teacher-Designed Feedback Forms

This CAT is a standard and widely used method and thus, was used in this experiment together with other (previously discussed) CATs since analyzing the results in this method is much easier and also results can be compared over time. However, questions

designed in accordance with this CAT should be more general and therefore, cannot provide instructors with detailed and to-the-point results. In this experiment, some simple and course-specific evaluation questions were also prepared in addition to other assessment questions in multiple-choice formats.

One of the advantages of this method is that it can be effective for almost any type of course and presentation. This method was used in this experiment to gain information about different feedback results in different teaching scenarios and to track changes in both short- and long-terms. To yield the best outcome, it is recommended that this method be used in multiple back-to-back sessions in order to provide guidelines to instructors as to how to improve the course materials and delivery techniques.

### 4.3.9    Group-Work Evaluations

As was previously stated, students in Group B worked in teams of two during their mystery lecture. Therefore, this CAT was selected to evaluate their cooperative and collaborative learning. This method can help both students and instructors understand the pros and cons of group work. Evaluating the result of working in a group should be considered separately from the sole effect of the learning tool since sometimes working in a group may reduce the efficiency by raising students' expectations or some students may even dislike group work [153]. As such, the effect of working in groups should be taken into consideration by itself.

Most of the mobile technologies used in educational environments were targeted towards a short unit or cycle of activity that lasts at most a few weeks, and may not have been necessarily part of a school's existing curriculum [154]. In contrast, one problem this research tried to address was to assess the impact of CAM-ART not only in short-term but also in long-term learning. Given that end-of-semester exams are always a critical part for assessment since students usually take exams much more seriously, a list of long-term evaluation assessment questions related to this experiment was incorporated into the course final exam. Nonetheless, students were not given prior notice about this assessment nor they were told that this part of the exam would be graded separately from the rest. This was essential to make sure that they would treat the assessment questions with the same level of honesty and attention as they did the regular exam questions. Students in Group B (test group) were also given Likert-scale and open-ended questions asking (1) what they liked and did not like about the experience, (2) what they thought the activity had helped them to learn, and (3) if they had any suggestions for improvement. The results and analysis of the assessment is provided in the following Section.

## 4.4 Data Analysis and Results

As previously discussed, three similar assessment tests were given to all participating students both before and after the class, as well as one month later during the final course exam (see Table 4.1). As shown in Table 4.3, in the post-test and long-term test, the mean grade and the standard deviation of the grades for both groups A and B are very similar.

However, looking at the pre-test results, it is evident that Group A (control group) had a stronger background knowledge about the course topic compared to Group B (test group). In this Table, each group had 8 participants and the grades were out of 18.

Table 4.3: Statistical analysis of results obtained from pre-test, post-test, and long-term test (mean and standard deviation).

| Group | Pre-Test | | Post-Test | | Long-Term Test | |
|---|---|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| A (Control) | 7.75 | 2.66 | 12 | 2.39 | 11.13 | 2.42 |
| B (Test) | 5.25 | 2.96 | 12.5 | 2.33 | 11.63 | 3.16 |

Since there were 8 data points in each group, the t-test could not be effectively performed for the comparison of the results. Therefore, the Mann-Whitney test was used. This test is a non-parametric statistics test and can handle small sample sizes and is commonly used to compare data points of two different samples. The null hypothesis in this test considers similarity of the two populations while the alternative hypothesis considers the other way, especially when the particular population tends to have larger values than the other [155]. Results are presented in the following Subsections.

### 4.4.1 Comparison of pre-test and post-test results

In order to compare the results, the improvement percentage between the pre-lecture and post-lecture tests was calculated. Equation 4.1 was used to determine the improvement percentage for each student:

$$\text{Improvment \%} = \frac{\text{Post\_lecture grade} - \text{Pre\_lecture grade}}{\text{Pre\_lecture grade}} \times 100 \tag{4.1}$$

However, since one of the students did not answer any of the questions in the pre-lecture test and thus received a zero grade, the corresponding data point had to be eliminated to be able to perform the Mann-Whitney test.

Following are the results of the Mann-Whitney test, using Mini-Tab 16 [156]:

```
Mann-Whitney Test and CI: Group A, Group B

                    N   Median
Group A             8     38.1
Group B             7    100.0


Point estimate for ETA1-ETA2 is -61.9
95.7 Percent CI for ETA1-ETA2 is (-150.0, 20.0)
W = 49.0
Test of ETA1 = ETA2 vs ETA1 > ETA2
Cannot reject since W is < 64.0
```

According to the test results, the null hypothesis which states that values in Group B are larger than the ones in Group A cannot be rejected.

### 4.4.2  *Comparison of pre-test and long-term test results*

Similar to Subsection 4.4.1, the Mann-Whitney test was also performed to compare the improvement between pre-lecture and long-term test results. The improvement percentage was calculated according to Equation 4.2.

$$\text{Improvment \%} = \frac{\text{Long term grade} - \text{Pre\_lecture grade}}{\text{Pre\_lecture grade}} \times 100 \qquad (4.2)$$

And the following results were obtained in Mini-Tab 16 [156]:

```
Mann-Whitney Test and CI: Group A-Long Term, Group B-Long Term

                        N   Median

Group A-Long Term       8    38.1

Group B-Long Term       7    77.8


Point estimate for ETA1-ETA2 is -35.5

95.7 Percent CI for ETA1-ETA2 is (-106.7, 17.9)

W = 51.0

Test of ETA1 = ETA2 vs ETA1 > ETA2

Cannot reject since W is < 64.0
```

Again, the null hypothesis which states that values in Group B are larger than the ones in Group A cannot be rejected. The obtained values indicated a statistically significant difference between the improvement percentages of the group that carried out CAM-ART in classroom (Group B). Consequently, an evaluation questionnaire was given to Group B participants to evaluate their attitude towards using CAM-ART. The results of this questionnaire are discussed in Subsection 4.4.3.

### 4.4.3 Evaluation

At the end of the experiment, Group B students answered an evaluation questionnaire regarding their attitude towards using CAM-ART and its impact on their learning experience. Through the analysis of the open-ended questions of the questionnaire, it was found that students felt more interested in and motivated towards the topic. Respondents mentioned that they experienced a much more interactive learning environment compared

to traditional and lecture-based techniques. However, a few students stated that they had difficulty working simultaneously with CAM-ART and concentrating on the lecture. All in all, the majority of students in Group B were satisfied with the new AR learning tool. Figure 4.8 shows students' responses with regard to the impact of the CAM-ART on their learning experience. The complete feedback questionnaire is presented in Appendix D.
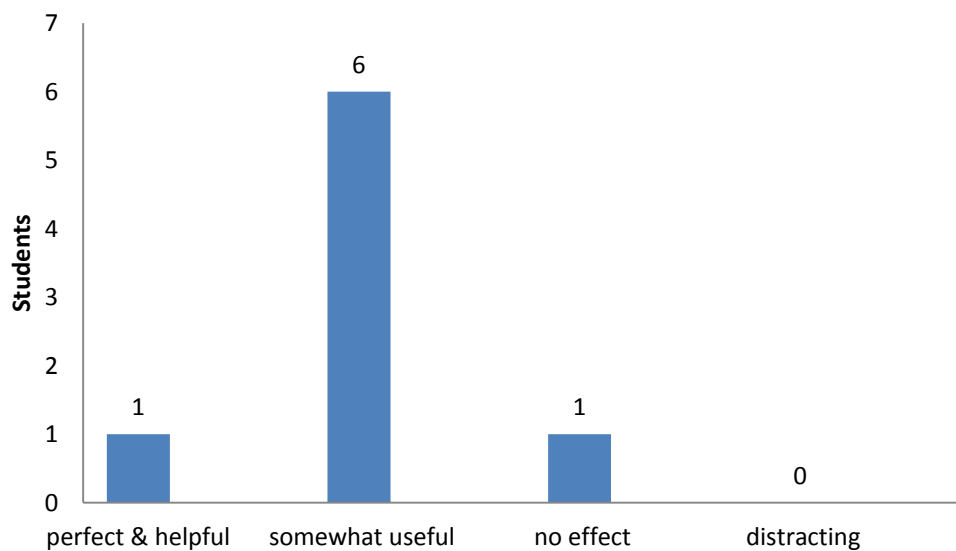


Figure 4.8: Students' responses to the statement "describe the impact of CAM-ART on your learning".

In addition, the responses given to two five-point Likert scale questions revealed that most students rated CAM-ART as an effective tool and would highly recommended it to other fellow students and instructors (see Figure 4.9).
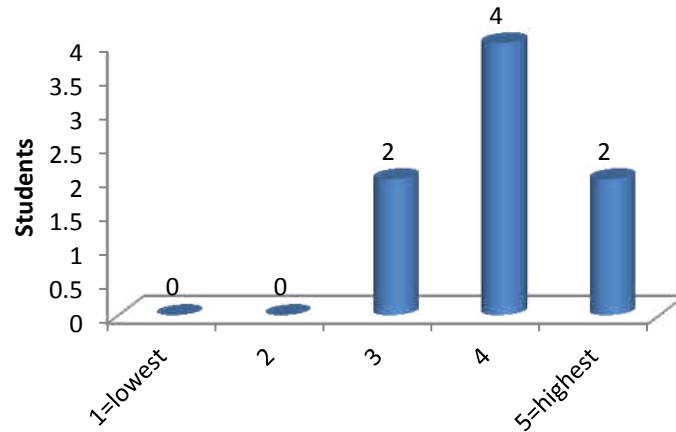
(a) How do you rate your learning experience today?
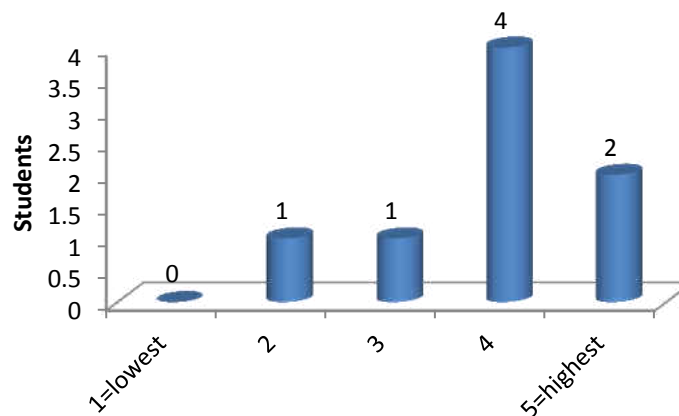


(b) How likely would you be to recommend this (or similar AR) tool to your schoolmates

and instructors for other courses?

Figure 4.9: Students' responses to sample statements from the post-experiment questionnaire.

Another interesting observation made through analyzing the results was that students who used CAM-ART left fewer blank answers in both post-lecture and long-term tests compared to their pre-lecture test. As seen in Table 4.4, the total number of blank

answers decreased by 66 in post-test and 68 in long-term test for Group B students, almost twice as much as the same measure for Group A students (35 for post-test and 27 for long-term test). It is imperative that a non-blank answer is not necessarily a correct answer. However, knowing that Group A students started with a higher prior knowledge (less blank answers compared to Group B students), it was interesting to observe that eventually, Group B caught up and ended up leaving less blank answers in the long-term period. At least, this can be a good indicator that Group B students gained more self-confidence and better technical knowledge after using CAM-ART.

Table 4.4: Number of blank answers in each test for the two groups.

| Group | Pre-Test | Post-Test | Long-Term Test |
|---|---|---|---|
| A (Control) | 35 | 0 | 8 |
| B (Test) | 73 | 7 | 5 |

## 4.5 Discussions and Conclusions

Taking into account the results of performance data analysis, it can be concluded that although CAM-ART still has room for improvement, it has illustrated a considerable potential to be used as an effective pedagogical tool to supplement the traditional classroom setting and ordinary textbooks [157]. However, one should not lose sight of the potential pitfalls of using technology in the classroom. For instance, Dede and Barab [158] discussed that in their experiments, teachers and students found AR tools interactive, situated, collaborative and highly engaging. However, they also mentioned that while AR provided potentially transformative added values, it simultaneously

presented unique technological, managerial, and cognitive challenges to teaching and learning. This immersive interface thus illustrates both considerable potential and complex challenges to implementation. Hence, in all future implementation strategies, learners should be engaged as active participants in their learning by focusing their attention on critical elements, encouraging abstraction of common themes or procedures (principles), and evaluating their own progress toward understanding [159].

The goal of the experiment described in this Chapter was to design, implement, and systematically assess a context-aware mobile AR information delivery tool (referred to as CAM-ART). In particular, an ordinary textbook was enhanced using 3D and other multimedia virtual information. The developed AR tool was used in an undergraduate-level construction and civil engineering course with a total enrollment of 16 students, and its impact on and benefits to students' learning was evaluated. The findings from this experiment suggested that CAM-ART can provide better learning support capabilities for barrier removal between students and technology. In addition, it provided an interactive workspace and encouraged collaboration and interaction between students and the course contents by immersing participants in a multimedia-enabled learning environment.

# CHAPTER 5: EXPERIMENT 2: TECHNICAL CONTENT DELIVERY USING MOBILE AUGMENTED REALITY (AR)

## 5.1 Overview

Considering the promising results of the first experiment on using augmented reality (AR) in construction education, a second experiment was designed and conducted with the aim of evaluating other aspects of using mobile AR pedagogical tools to support the hypothesis of this thesis. In particular, the goal of the second experiment was to test the effectiveness of using AR instructions in a building design and assembly task as part of an engineering course. In addition to the technology design and implementation, and in order to systematically validate the designed pedagogical methodology, students' performance data and their evaluation and feedback were also collected and analyzed. Of particular interest was to investigate whether students' communication and teamwork abilities could be improved. The following Sections provide a detailed description of the technical and pedagogical aspects of the designed methodology, validation, and results of the experiment.

## 5.2 Methodology

In this experiment, a location-based channel and an image-based channel (as described earlier in Chapter 3) were created and used. Using the location-based channel, users can hold their mobile devices and look around to see the virtual objects at the position of

points of interest (POIs). In the designed experiment, an AR instructor (avatar) was created using location-based channels. Students first scanned the QR code and then held their mobile devices towards the instructor avatar (placed on a specific POI in the classroom) to access a step-by-step video guide on how to conduct the experiment. As illustrated in Figure 5.1, each step was shown as a thumbnail that could be selected by students. Each thumbnail was linked to a video describing the details of that step. Therefore, students could watch any part of the instructions at their own pace and for any number of times during the course of the experiment. More information about the details of the supporting Hypertext Preprocessor (PHP) programming code in the location-based channel can be found in Appendix E.
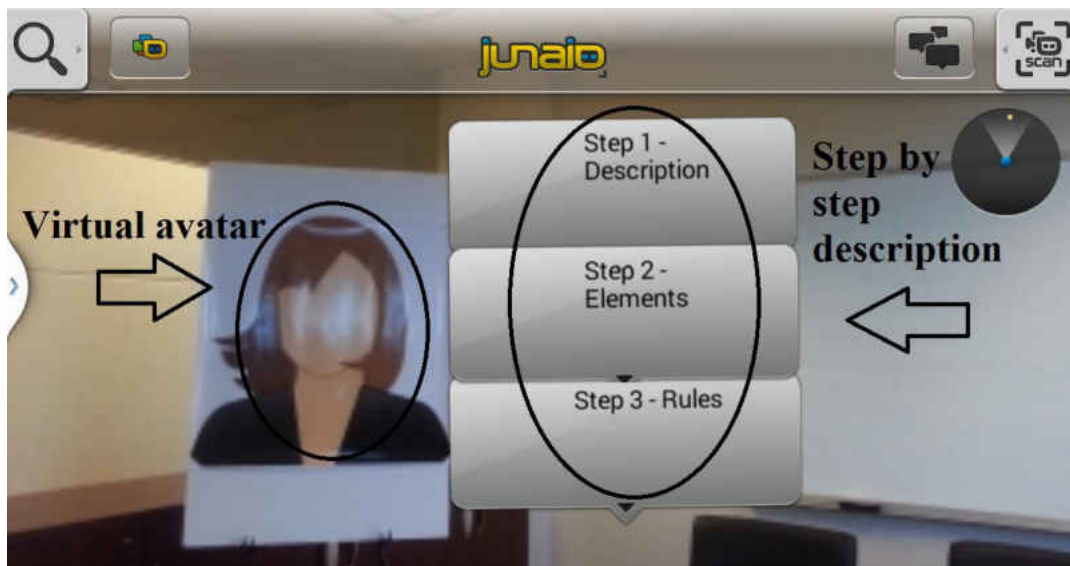


Figure 5.1: Students used a location-based channel to receive step-by-step video instructions from a virtual avatar.

In contrast to location-based channels, image-based channels are used to attach or "glue" virtual 3D models and other multimedia to any real object. In the designed experiment, image-based channels were used to attach 2D/3D virtual information to each model building element. In this case, students were able to receive design information (e.g. material type, weight, cost, dimensions) about each element of the model building by moving their mobile devices over the tracking images and scanning that image (see Figure 5.2). Details of the supporting PHP programming code of image-based channel of this experiment can be found in Appendix F.



Figure 5.2: 3D virtual information displayed over the view of a real model building element.

Moreover, in order to evaluate its pedagogical impact, the designed mobile AR application was tested in real classroom settings. In particular, and to compare the

combined effect of employing a virtual instructor and delivering contextual information via an AR interface, students were asked to participate in two separate model building design and assembly experiments. In the first experiment, participants were provided with a traditional (print) manual that contained detailed instructions and design information, while in the second experiment, students used their mobile devices to receive instructions as well as design information from the designed AR application. More information about these experiments, their effects on student learning, and the final evaluation results are presented in the following Subsections.

### 5.2.1 Participants and Group Management

Participants were junior and senior level construction and civil engineering students who were enrolled in CGN3700C (Civil Engineering Measurements) in Fall 2013. 60 students participated in these experiments with an average age of 24. The experiments were built into the course as two stand-alone laboratory modules. Participants were not given any prior information regarding the details of the experiments and had no previous experience with AR in an educational context. This was necessary to make sure that all students were at the same level of practical knowledge prior to the experiments.

Students were divided into two control and test groups. Each group conducted the experiment separately to avoid any possible influence on the performance of the other group. Students were divided into two groups of 30 students working in groups of three. Students in the control group deployed ordinary printed manual instructions, and students in the experiment group took benefit of the designed AR application and virtual

instructor. Moreover, since some researchers have found that gender is correlated with spatial ability [160], groups consisted of either male or female students to also examine possible gender effects.

### 5.2.2 Experiment Procedure

As described earlier, two different experiments were created and conducted in two separate sessions:

- Session 1: Printed manual experiment (control group)
- Session 2: AR instructor experiment (test group)

In each session, participants were first instructed to the overall goals of the experiment. Following this brief introduction, no additional description was provided and groups were asked to begin the experiment.

As shown in Figure 5.3, in session 1 experiment, each group was given a print manual that contained descriptions of steps needed to complete the model building design and assembly task. All necessary design and performance data was also included in the manual. Students were asked to follow the manual to determine what they need to do and make their decisions.

Figure 5.3: Students in control group used print manual instructions to design and assemble model buildings.

In session 2, on the other hand, each group was given a brief 2-page handout containing only two QR codes linked to the location-based channel (i.e. virtual instructor) and a third QR code that provided linkage to the image-based channel (i.e. design information). As shown in Figure 5.4, a large cardboard cut-out of an avatar was placed in one corner of the room. Students used their mobile devices (smartphones or tablets) to scan the first two QR codes and then turned in the direction of the avatar cut-out to watch instructional videos.

Figure 5.4: Students in test group used their mobile devices to receive instructions from a virtual avatar.

Next, students used their mobile devices to scan the third QR code and gain access to design information of model building elements. As shown in Figure 5.5, the information was visually overlaid on top of each building element as soon as the tracking image attached to that element was scanned and detected by the camera of a mobile device.

Figure 5.5: Students scanned the tracking image attached to each building element to access information.

### 5.2.3   Experiment Design

As previously stated, the ultimate goal of this experiment was to design and build a model structure following certain design and performance criteria. Each group received a package of 60 wood elements that could be assembled into a variety of building shapes. These elements were divided into three different categories of columns, beams, and junctions and finishing. At the beginning of the experiment, each team was asked to use three labels provided in the package to sort all pieces into these three categories. In

addition to having three different element types for the structure, elements were also grouped into three materials namely concrete, steel, or wood. This was to encourage students to select the elements carefully considering both shape and material properties such that the final building performance would be optimal. As described earlier, information relevant to each element was provided either in the print manual (for the control group) or through the AR instructor (for the test group).

Students had to also follow certain design and performance rules. Any deviation from these rules would be considered a design error and could add a penalty to the group's final score. Each group's performance was evaluated based upon 3 design measures (namely building volume, number of elements, and completion time) and 3 performance measures (namely building cost, carbon footprint, and fire resistance). The goal was to make a model building with a volume as close to 30,000 cm$^3$ as possible, in the least possible time while using the fewest number of elements. The final building model had to be at minimum cost, and result in the least carbon footprint and maximum fire resistance. Each group was provided with supplementary tables to help calculate all design and performance factors for their building model. The final ranking of each group was then calculated relative to the performance of all 20 groups. Detailed information about calculating the ranking of each group and the final results are provided in the following Sections.

## 5.3 Assessment Techniques

In order to evaluate and compare the task load of the two experiments, the NASA task load index (NASA TLX) was used as an assessment technique. This subjective, multidimensional assessment tool is used to measure workload estimates associated with a task [161]. It considers 6 subscales that represent somewhat independent clusters of variables indicating workload. The first three subscales related to demands on a person are (1) mental demand, (2) physical demand, and (3) temporal demand. The next three subscales related to person-task interaction are (1) frustration, (2) effort, and (3) own performance [162]. Table 5.1 contains a detailed description of theses subscales. The NASA TLX method assumes that some combinations of these dimensions are likely to represent the "workload" experienced by most people performing most tasks. The complete NASA TLX questionnaire is presented in Appendix G.

Table 5.1: Description of NASA TLX subscales.

| NASA TLX Subscale | Description |
|---|---|
| Mental Demand | How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex? |
| Physical Demand | How much physical activity was required? Was the task easy or demanding, slack or strenuous? |
| Temporal Demand | How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid? |
| Frustration | How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task? |
| Effort | How hard did you have to work (mentally and physically) to accomplish your level of performance? |
| Own Performance | How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals? |

Additionally, at the conclusion of each group's work, a post-experiment assessment was taken from the students in that group regarding their experience throughout the session. In this evaluation, students answered a number of multiple choice teacher-designed feedback questions and group-work evaluations [163].

## 5.4  Data Analysis and Results

### 5.4.1  Experiment Results

Table 5.2 lists the results obtained from each session with regard to the 3 design measures described in the previous Sections. In this table, the average and coefficient of variance (CV) of each factor considering the performance of all 10 groups in each session are shown. The building volume is calculated by multiplying the elevation of the topmost

point on the building by the building area. Also, the value of CV is calculated using Equation 5.1,

$$CV = \frac{Standard\ Deviation}{Mean}$$ (5.1)

Table 5.2: Design measures statistics for control and test groups.

| Session | Building Volume (cm3) | | Number of Elements | | Completion Time (min) | |
|---|---|---|---|---|---|---|
| | Average | CV | Average | CV | Average | CV |
| 1 (Control) | 34,801 | 0.35652 | 33 | 0.18 | 69 | 0.10 |
| 2 (Test) | 31,015 | 0.15554 | 29 | 0.24 | 73 | 0.18 |

As shown in this Table, the average building volume in the test group (that used the designed AR application for instruction and information delivery) was closer to the target value of 30,000 cm³. Also, the test group used fewer elements in their final design but spent slightly more time on the experiment. The difference in completion time was about 4 minutes on average which can be mostly attributed to the fact that students in this group had to spend some time upfront to learn how to use their mobile devices to retrieve instructional videos and element information. It was also observed during the two experiments that compared to the control group, students in the test group showed more enthusiasm and involvement in the design process and spent larger portions of their experiment time on communication and exchanging ideas.

Table 5.3 lists the results obtained from each session with regard to the 3 performance measures described in the previous Section. In this table, the average and CV of each factor considering the performance of all 10 groups in each session are shown.

Table 5.3: Performance measures statistics for control and test groups.

| Session | Building Cost ($) | | Embodied Carbon (ton) | | Fire Resistance (hr) | |
|---|---|---|---|---|---|---|
| | Average | CV | Average | CV | Average | CV |
| 1 (Control) | 3,391,140 | 0.479776 | 3,665 | 0.6095 | 2.515 | 0.2136 |
| 2 (Test) | 4,412,160 | 0.436926 | 5,270 | 0.6259 | 2.361 | 0.0751 |

As it is shown in this Table, the average building cost and embodied carbon is significantly less for the control group (session 1) than the test group (session 2). However, the average fire resistance for both groups is statistically similar, considering the CV values. It can be thus, concluded that the control group did generally better as far as performance measures were concerned. One contributing factor to this result is that students in the test group had to scan each building element one by one and for as many times as needed during the experiment in order to retrieve information, while students in the control group had this information readily available in their print manuals during the entire time of the experiment. The need for the repetitive use of mobile devices to retrieve information may have caused frustration in the test group students. This problem coupled with the fact that students were under pressure to finish their designs on time might have ultimately resulted in less efficient designs in the test group.

### 5.4.2 NASA TLX Results

Figure 5.6 shows the results obtained from the control and test groups with respect to the 6 NASA TLX subscales. It is clear that the students in the test group felt more frustrated, but at the same time, believed that they put more effort and performed relatively better.

## Control Group (Session 1)



## Test Group (Session 2)
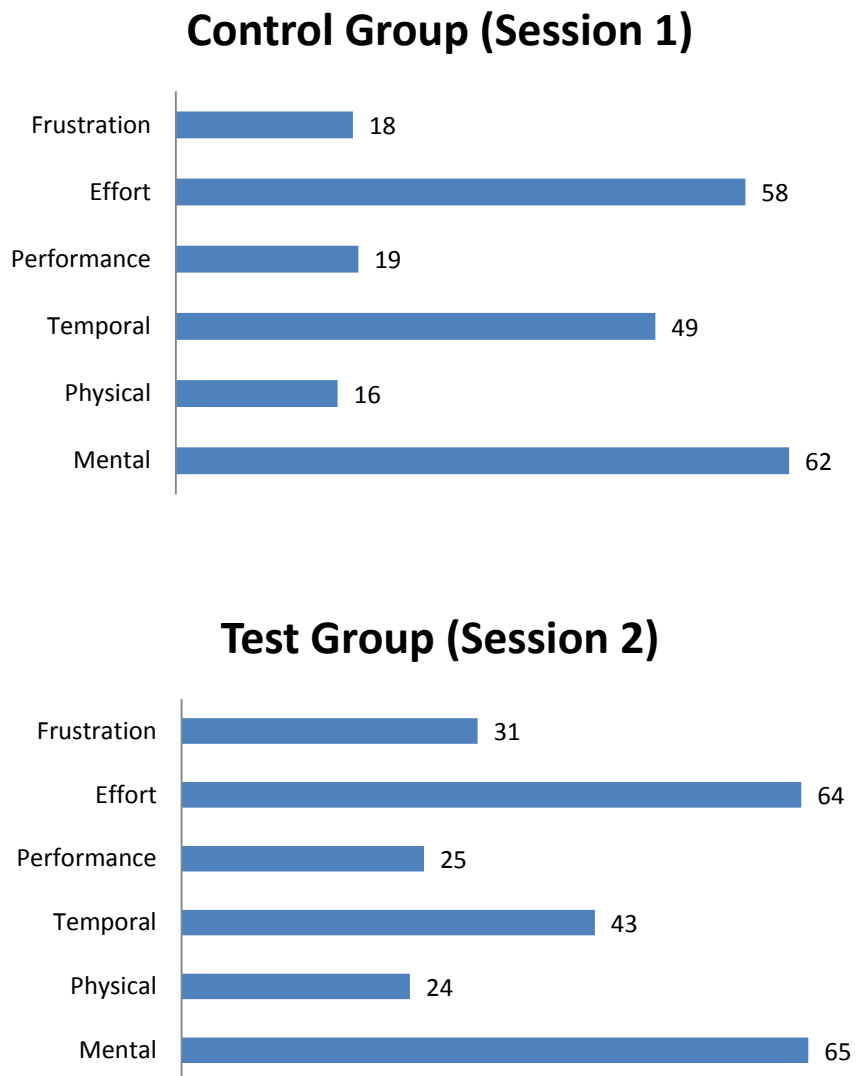


Figure 5.6: Calculated NASA TLX subscales for control and test groups.

Additionally, according to the NASA TLX final assessment results, as shown in Figure 5.7, the average workload score achieved by both groups are almost the same. However, besides the time and effort students in both groups had to spend on the actual building design and assembly task, students in the test group had to spend extra time and effort to first learn how to work with the AR application to extract information. In other words, relative to the control group, the workload of students in the test group was divided between a primary activity (i.e. building design and assembly) and a secondary activity (i.e. learning how to use an application). Therefore, it is clear that the test group students were under less workload as far as the actual building design and assembly task was concerned.
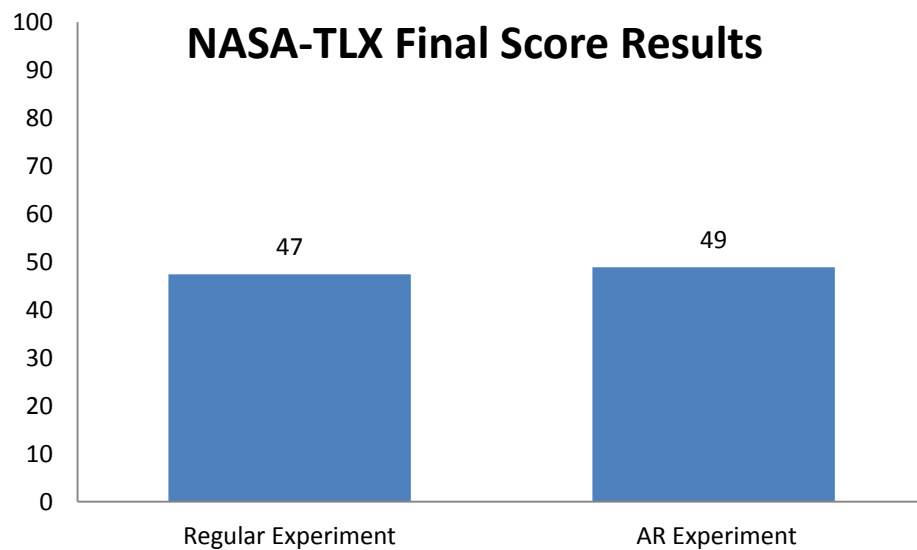


Figure 5.7: NASA TLX final score results.

### 5.4.3   Post-experiment assessment results

#### 5.4.3.1 <u>Control Group (Session 1)</u>

According to the results of the post-experiment assessment taken at the conclusion of the building design and assembly task in session 1, 97% of respondents stated that the print manual instructions about the overall goal and steps of the experiment were "very clear" or "clear". Also, 79% of respondents stated that it was "very easy" to retrieve design and performance information from the print manual (See Figure 5.8).
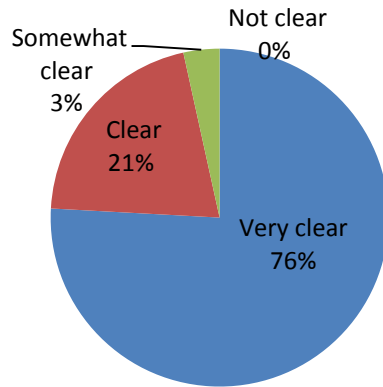
(a)
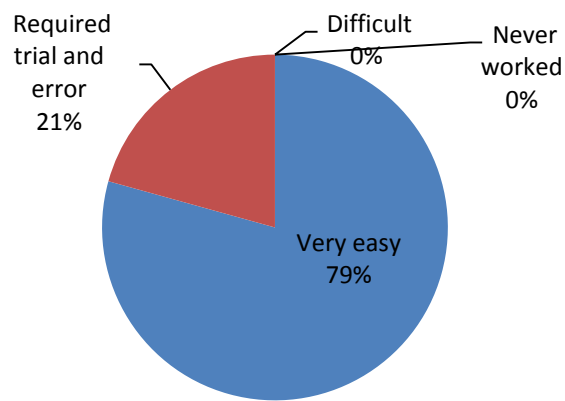


(b)

Figure 5.8: In session 1, (a) 97% of students indicated that the manual instructions were "very clear" or "clear" and, (b) 79% found it to be "very easy" to extract required information.

Students were also asked to estimate the percentage of experiment time they spent on communicating with their team members. On average, 73% (standard deviation of 24%) of students' time was spent on communication and exchanging ideas. Moreover, students believed that on a scale of 0-100, the level of "interactivity" of the experiment was 86%

(standard deviation of 17%). In order to evaluate the role of teamwork and collaboration on individual's performance, each student was also asked to estimate the percentage of work he or she could have completed alone had he or she been given twice the time. The average response to this question was 90% (standard deviation of 14%). Finally, participants rated their overall assessment of the experiment on a scale of 1-5 (1=lowest, 5=highest) at 4 (standard deviation of 0.6). The detailed feedback questionnaire is presented in Appendix H.

### 5.4.3.2 *Test Group (Session 2)*

According to the results of the post-experiment assessment taken at the conclusion of the building design and assembly task in session 2, 79% of respondents stated that the instructions delivered through the mobile AR application were "very effective" or "effective" in helping them obtain necessary information during the experiment (See Figure 5.9).
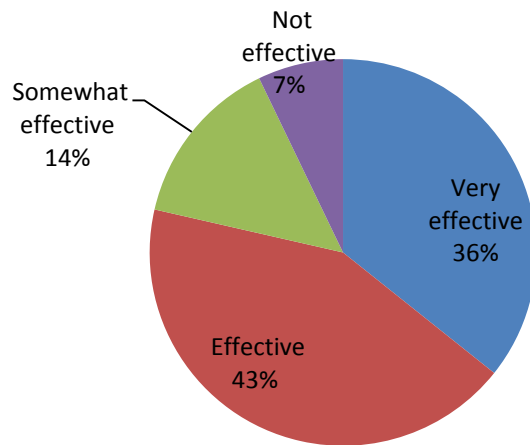
Figure 5.9: In session 2, 79% of students responded that the mobile AR instructor was "very effective" or "effective" in obtaining necessary information for the experiment.

Only 36% of respondents stated that it was "very easy" to retrieve design and performance information using the mobile AR application while 54% believed this required several rounds of trial and error. Students were also asked to estimate the percentage of experiment time they spent on communicating with their team members. On average, 87% (standard deviation of 18%) of students' time was spent on communication and exchanging ideas. Moreover, 89% of students believed that the designed mobile AR application was "interactive". In order to evaluate the role of teamwork and collaboration on individual's performance, each student was also asked to estimate the percentage of work he or she could have completed alone had he or she been given twice the time. The average response to this question was 89% (standard deviation of 13%). Additionally, as shown in Figure 5.10, 92% of students stated that the designed mobile AR application was "very helpful" or "somewhat useful" in their learning process

while only 4% of respondents stated that they were "distracted" by the application during the experiment.
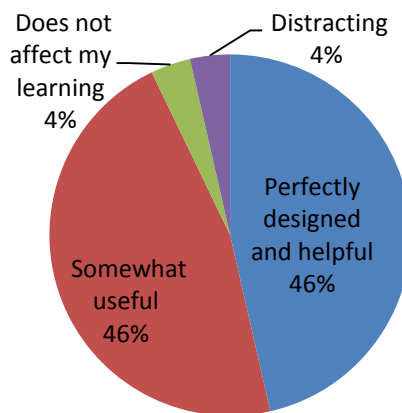


Figure 5.10: In session 2, 92% of students indicated that the AR application was very helpful or somewhat useful.

Moreover, a solid majority of 86% had a positive view about the possibility of using mobile AR applications in other courses for the purpose of learning abstract and difficult-to-understand topics. Along the same line, on a scale of 1-5 (1=lowest, 5=highest), with a mean of 4 (standard deviation of 1.3), students expressed their willingness to recommend the designed mobile AR application (or a similar AR tool) to their schoolmates and instructors for use in other courses. Finally, participants rated their overall assessment of the experiment on a scale of 1-5 (1=lowest, 5=highest) at 4 (standard Deviation of 0.9). Figure 5.11 shows the breakdown of student responses (on a Likert scale of 1-5) to two key questions with regard to the effectiveness of the virtual instructor and the AR

information delivery. The detailed feedback questionnaire is also presented in Appendix I.
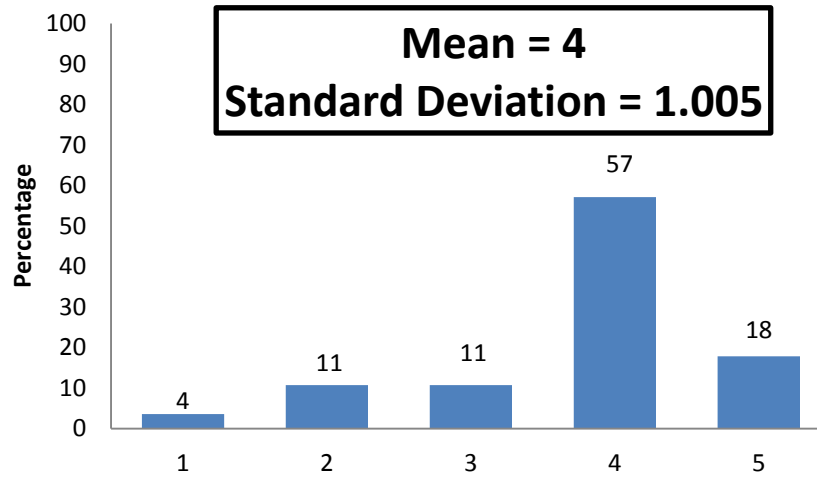


(a)
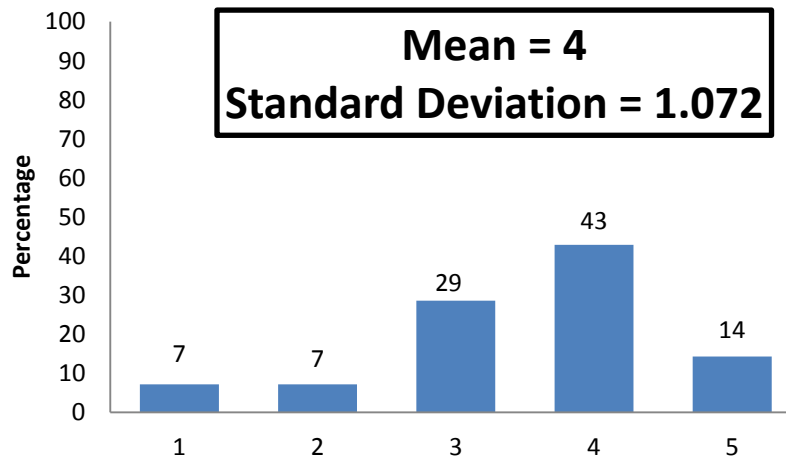


(b)

Figure 5.11: Student rating of the effectiveness of the (a) virtual instructor, and (b) AR information delivery platform, on a scale of 1-5 (1=lowest, 5=highest).

## 5.5  Discussions and Conclusions

The main goal of this experiment was to design, implement, and systematically assess the pedagogical value of an AR-based instruction and information delivery tool to student learning in a large-scale classroom setting at a university level. For this purpose, 60 undergraduate construction and civil engineering students participated in two separate (control and test) building design and assembly experiments. Student performance data and perception was collected and analyzed in both experiments in an effort to assess the benefits of using a virtual instructor and information delivery through AR compared to traditional content delivery using print manuals. A total of 6 measures (3 design measures and 3 performance measures) were used to evaluate each group's performance. Furthermore, the NASA TLX method was used to check students' workload during the experiments and finally, evaluation forms were used to perform an individual evaluation of each student at the conclusion of each experiment.

In general, and considering the values calculated for the 6 design and performance factors (namely building volume, number of elements, completion time, building cost, embodied carbon, and fire resistance), both control and test groups showed a satisfactory performance. However, compared to the control group, students in the test group spent an average of 4 minutes more to complete their tasks which can be mainly attributed to the fact that they needed to learn how to use the AR application before they could proceed with the actual design and assembly task. Further analysis of data revealed that although both groups achieved statistically similar results to most extents, students in the test

group were also introduced to a new technology and showed more interest and involvement in the experiment. Moreover, according to the NASA TLX results, despite the fact that the students in the test group had to put more effort and at points were more frustrated, they performed generally better, used more mental and physical abilities, and were able to more effectively communicate and exchange ideas. Also, at the conclusion of the experiment, the test group students had very positive views about the possibility of using mobile AR applications in other courses for the purpose of learning abstract and difficult-to-understand topics [164].

It can thus be concluded that if students receive proper instructions and become more familiar with new technologies through preliminary training, they are more likely to perform better in comparison with those attending regular classroom sessions. It is imperative that this will ultimately motivate students to participate more in class activities, communicate effectively, and play an active role in their learning process.

# CHAPTER 6: CONCLUSIONS AND FUTURE WORK

## 6.1 Conclusions

This research aimed at using mobile context-aware augmented reality (AR) in construction and civil engineering instruction and information delivery systems. The main motivation of this research was that despite today's students may have a very good knowledge and understanding about state-of-the-art visualization technologies such as virtual reality (VR) and AR, neither them nor instructors are taking full advantage of these advances in educational settings. Following a thorough literature review of existing instructional technologies and information delivery systems in construction and civil engineering education, the author designed and implemented a pedagogical methodology based on mobile AR to help improve the quality of learning and retention of information in engineering education through transforming traditional instructional delivery techniques into technology-based learning. In order to test the pedagogical value of the developed tools on students' learning, two different sets of experiments were conducted on undergraduate students enrolled in the construction and civil engineering programs at the University of Central Florida (UCF). During both experiments, students used their smartphones or tablet devices to first download a mobile application which enabled them to access computer-generated information (e.g. 2D images, 3D models, movies, and sound) augmented on ordinary print materials (e.g. textbooks, tracking images glued to physical elements).

In the first experiment, parts of an ordinary engineering textbook were enhanced using 3D and multimedia visual information. Students were then asked to use their smartphones or tablet devices to navigate through their textbooks and receive on-demand virtual information corresponding to different figures and diagrams in their books. During this experiment, an academic assessment process was followed to validate the effectiveness of the developed instructional material delivery technique. To this end, the author conducted a pilot assessment study by dividing a class of 16 students into two groups. The control group attended a regular (traditional style) lecture, while the test group was asked to interact with the lecture material using their mobile devices and AR pop-up books. Data describing student performance was collected from both groups and analyzed using several classroom assessment techniques (CAT) adopted by Cross and Angelo [152].

In the second experiment, a mobile AR information delivery application was designed and used to test students' performance in a building design and assembly project. For this purpose, a virtual instructor was used to provide students with the experiment procedure and an AR image tracking system was designed to enhance the selection and assembly of elements by providing relevant design and performance information to the students. Sixty undergraduate construction and civil engineering students participated in this experiment. Similar to the first experiment, students were divided into two control and test groups. In each group, students were further divided into groups of three. In the control group, participants used printed manual instructions while in the test group, students were asked to download and use the developed mobile AR platform to receive required information

when designing and assembling their model buildings. At the conclusion of the experiment, data about the final assembled model building as well as student workload, performance and satisfaction was collected from each student group to validate the real impact of the developed tool on students' learning and motivation.

The results of both experiments indicated that the majority of students rated mobile AR tools as effective educational platforms and suggested that they (or similar tools) should be as well used in other courses. In general, it was found that AR visual simulation coupled with collaboration and interaction can provide multiple affordances in support of technology-based and situated learning. Future work in this study will include adding new features such as mobile interaction, testing the developed mobile AR tools in outdoor environments such as construction jobsites to train workers, assessing the pedagogical aspects using larger and more diverse student and trainee populations, and ultimately, expanding the application domain to other STEM disciplines. In support of these long-term goals and to encourage future work in this area, the author has already taken some preliminary steps which are described in the following Section.

## 6.2 Directions for Future Work

A review of existing AR-based information delivery platforms reveals that in most existing tools, visual data is presented to the user in only static forms [124, 165, 166]. This means that the presented visual content only captures snapshots of the entire project lifecycle by displaying particular information about an object (e.g. column, beam, or slab)

that is not normally subject to change. A good example of such information for a concrete slab could be its dimensions (width, length, and thickness), or a list of its preceding or succeeding activities that can be normally retrieved from a project schedule which may be rarely updated. In reality, however, project entities and schedule is subject to change and therefore, relying solely on static information may lead to the delivery of unreliable information with no real practical value. Therefore, besides its robust design and ease of use, an information delivery system should be also capable of dynamically communicating the correct data in proper time with field personnel and project decision-makers. The idea of presenting dynamic information to users has been explored in areas other than construction engineering. For instance, recently, Peiris et al. [167] designed an AR tool to dynamically display varying temperature readings on a single marker printed on temperature-sensitive paper. In this work, parts of the marker pattern would become invisible in certain temperature ranges, hence creating the illusion of a new marker that would then be detected by the application. Another example of dynamic AR visualization is the robot-assisted surgical system used to present force information through sensory substitution [168]. In this system, a surgeon applies force to the manipulated tissue which is displayed over a patient's body. The force is graphically represented and overlaid on the streaming video from the camera, allowing the surgeon to examine the effect of the force exerted on the patient's body at any given time.

Considering the existing literature, one of the promising directions for future work could be the development of a dynamic context-aware construction information delivery

platform that is capable of delivering constantly updated visual information to field personnel in mobile AR. The following Subsection reports on the preliminary steps taken by the author to help make this vision a reality.

### 6.2.1   *Proposed Methodology*

The author used Junaio's Location-based channels to create dynamically changing AR visualizations. As described in previous Chapters, location-based channels enable users to view the real world through the built-in camera of their mobile devices while the application overlays virtual information about Points of Interest (POIs) located in the user's surrounding as soon as they are detected. This allows field personnel to use their mobile devices (e.g. smartphones, tablet PCs) which have both input (through built-in camera) and output (through display) features to access supplementary information about project entities such as equipment (e.g. position, payload, capacity, dimensions, work plan), or material (e.g. supplier, inventory information, installation instructions, specifications). This can help decision-makers make more informed and timely decisions that comply with the latest conditions in the field.

A series of proof-of-concept experiments were conducted in this research. As shown in Figure 6.1, users first scan a Quick Response (QR) code using the built-in camera of their web-enabled handheld devices to access the proper information channel. This QR code can be printed on a piece of paper and carried by field operators or project engineers as they are deployed to different locations on the jobsite. Once the QR code is scanned, there will be no need for subsequent scanning as long as the AR application is running on

the mobile device. Then, as the mobile device points towards the direction of a specified POI (which is defined using its global coordinates expressed in terms of longitude, latitude, and altitude), the virtual information relevant to that POI is displayed on top of the real world scene.



Figure 6.1: Scanning a QR code in a construction jobsite.

### 6.2.2 *Implementation and Results*

In order to evaluate the applicability of mobile AR information delivery in practical scenarios, two sets of proof-of-concept experiments were conducted. The following Subsections describe these experiments.

#### 6.2.2.1 *Stage 1 – indoor experiment*

The goal of this indoor experiment was to test if information can be shown dynamically using mobile AR in a controlled environment where the effect of ambient factors and noise is kept at minimum. In general, this is a necessary first step in technology implementation as it allows developers to identify and resolve design problems intrinsic to the system [169]. As shown in Figure 6.2, in this experiment, a medium-scale test

platform with an approximated area of 6 $m^2$ and a number of Remotely Controlled (RC) construction equipment models were used.



Figure 6.2: Laboratory setup for indoor AR information delivery experiments.

In this experiment, the user was asked to first scan the provided QR code and then move the mobile device over a previously specified path (with predetermined coordinates) while following a moving construction equipment model. As shown in Figure 6.3, the goal was to display the real time position of the moving equipment to the user. In a real operation involving large-scale equipment, such information can be captured by on-board instrumentation (OBI) or other types of sensors, transmitted to an online database, accessed in a ubiquitous manner, and continuously displayed by the AR application to the user.

X=3 and Y=3.2



X=3.5 and Y=3.5



X=3.7 and Y=3.8

Figure 6.3: Displaying the real tie 2D coordinates of a moving dump truck in mobile AR.

### 6.2.2.2 *Stage 2 – outdoor experiment*

The goal of the outdoor experiment was to test if the envisioned mobile AR information delivery application can be used in a real project setting to provide field personnel with meaningful context-aware information about different aspects of a project. For this

purpose, the author visited an active construction jobsite in Orlando, FL. Figure 6.4 shows the global coordinates of this jobsite as obtained from Google map [170, 171].
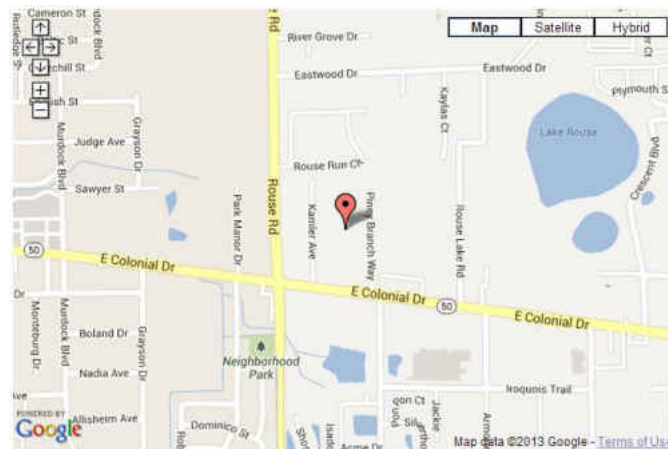


*Longitude = -81° 13' 16.9314"     Latitude = 28° 34' 13.944"     Altitude = 20.7 m*

Figure 6.4: Google map view of the construction jobsite.

In this experiment, a project engineer was asked to use her mobile device to access real time information about a dump truck. This information included the global position of the dump truck, relative distance to the user, and preceding and succeeding activities to the activity the dump truck was involved in. As shown in Figure 6.5, the project engineer was first instructed to select the dump truck from the real world view of the jobsite as captured by the mobile device. Then, at specific time stamps, relevant virtual information was delivered to her in form of dynamic text alerts and graphical layouts of the jobsite in which the position of the dump truck and the location of the next task were visually marked for more effective communication of the work plan.

Figure 6.5: Two steps of dumping and returning of a dumping truck cycle.

In the future, this approach can be further improved to provide users with more in-depth

information about a larger number of project entities (e.g. equipment, material stockpiles,

crews). In addition, algorithms can be designed to communicate with equipment OBI (through Bluetooth, WiFi, or other wireless technologies) and automatically collect and display more diverse sensory data to project engineers, site inspectors, and other field personnel.

## 6.3  Discussions and Closing Remarks

As context-aware information delivery becomes more common in the architecture, engineering and construction (AEC) domain and with the introduction of more complex sensor systems and data collection platforms, the main challenge is to provide users with the most updated and relevant information that is tailored to their specific needs at any given time during a project lifecycle. To this end, researchers have investigated the potential of advanced visualization techniques such as VR and AR and their benefits to improving field operations. So far, most existing information delivery tools that are based on such visualization technologies are capable of displaying only static information about project entities. For instance, users can retrieve information such as object dimensions that is very unlikely to change over time. In this Chapter, the goal was to demonstrate some potential areas of improvement by exploring the possibility of creating mobile AR information delivery tools that can automatically retrieve and display dynamic (constantly changing) information about project entities. To this end, the author evaluated whether her previously designed context-aware location-based AR application can be used to show information that is constantly changing.

In the future, more detailed experiments can be conducted to cover complex operations that include a more variety of construction equipment (e.g. dump trucks, loaders, excavators). Both static and dynamic information describing these objects (e.g. manufacturer's model, payload, maintenance record, engine condition, work schedule) can be captured from multiple sources (including OBI and other types of sensors, as well as digital project plans), transmitted to and stored in an online database, and retrieved and displayed on-demand to the field personnel or equipment operators.

The author believes that by enabling real time communication of operational information from field entities, these future directions will ultimately lead to the prospect of creating intelligent and inclusive location-based AR information delivery platforms that can assist in inspection, control, and monitoring of workflow processes.

# APPENDIX A: BACKGROUND SURVEY QUESTIONNAIER

**Background Survey**

**Fall 2012 – Fall 2013**

Using a smartphone or tablet PC in the classroom for the purpose of learning the course material may be distracting.

   Agree   Neutral   Disagree

I am a visual learner. I learn better when the instructor uses 2D/3D visualization or multimedia to teach abstract engineering and scientific topics.

   Agree   Neutral   Disagree

Compared to other engineering disciplines, instructors in civil and construction engineering use less technology in classroom.

   Agree   Neutral   Disagree

I learn better when working in a collaborative setting (e.g. working in a team) where I play a role in the learning process.

   Agree   Neutral   Disagree

Please answer the following questions regarding your **prior knowledge** about the following terms:

"Virtual Reality"
- Have never heard of it.
- Have heard of it but don't really know what it means.
- Have some idea what this means, but not too clear.
- Have a clear idea what this means and can explain it.

"Augmented Reality"
- Have never heard of it.
- Have heard of it but don't really know what it means.
- Have some idea what this means, but not too clear.
- Have a clear idea what this means and can explain it.

Please mark how confident do you feel to do the following:
Installing a mobile application on a smartphone or tablet device.
Very       Somewhat
Not very      Not at all

Using a mobile application on a smartphone or tablet device to get more information about a subject.

Very                               Somewhat
Not very                           Not at all

Working in a group where each student is using his/her own device to play a collaborative game related to the course topic.

Very                               Somewhat
Not very                           Not at all

If you selected "not very" or "not at all" in response to any of the above items, please briefly explain why.

………………………………………………………………………………………………

………………………………………………………………………………………………

I am a …………………. major.
Civil           Environmental        Construction        Other

I own a ………………….
Smartphone    Tablet device        Both               Neither

I am a ………………….
Male           Female

Please choose one of the learning types which you think more describes your personality
- Learning oriented: Students who like new challenges.
- Performance oriented: Students who are more worried about making errors than about learning.

# APPENDIX B: EXPERIMENT 1 - CAM-ART IMAGE-BASED CODE

**Search.php:**

```php
<?php

/**
 * @copyright  Copyright 2012 metaio GmbH. All rights reserved.
 * @link       http://www.metaio.com
 * @author     Frank Angermann
**/

require_once '../library/arel_xmlhelper.class.php';

//use the Arel Helper to start the output with arel

//start output
ArelXMLHelper::start(NULL,  WWW_ROOT  .  "/arel/index.php",  WWW_ROOT  .

"/resources/tracking_glue5.zip");

//video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
     "1",
     WWW_ROOT . "/resources/1.png",
     array(0,0,0), //translation
     array(3,3,3), //scale
     new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
     //rotation
     1 //CoordinateSystemID)
     );
//output the object
ArelXMLHelper::outputObject($oObject);

//image
$oObject = ArelXMLHelper::createGLUEModel3DFromMovie(
     "2",
     WWW_ROOT . "/resources/2.3G2
     array(0,0,0), //translation
     array(5,5,5), //scale
     new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
     //rotation
     2 //CoordinateSystemID)
     );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3D(
     "3",
     WWW_ROOT . "/resources/3.zip",
     NULL, //texture Path
     array(0,0,0), //translation
     array(40,40,40), //scale
```

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```php
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        3 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//image
$oObject = ArelXMLHelper::createGLUEModel3DFromMovie(
        "4",
        WWW_ROOT . "/resources/4.3G2",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        4 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//image
$oObject = ArelXMLHelper::createGLUEModel3DFromMovie(
        "5",
        WWW_ROOT . "/resources/5.3G2",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        5 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3D(
        "6",
        WWW_ROOT . "/resources/6.zip",
        NULL, //texture Path
        array(0,0,0), //translation
        array(30,30,30), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        6 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "7",
        WWW_ROOT . "/resources/7.png",
        array(0,0,0), //translation
        array(3,3,3), //scale
```

```php
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        7 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "8",
        WWW_ROOT . "/resources/8.png",
        array(0,0,0), //translation
        array(3,3,3), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        8 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "9",
        WWW_ROOT . "/resources/9.png",
        array(0,0,0), //translation
        array(3,3,3), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        9 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//image
$oObject = ArelXMLHelper::createGLUEModel3DFromMovie(
        "10",
        WWW_ROOT . "/resources/10.3G2",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        10 //CoordinateSystemID)
        );

//output the object
ArelXMLHelper::outputObject($oObject);

//image
$oObject = ArelXMLHelper::createGLUEModel3DFromMovie(
        "11",
        WWW_ROOT . "/resources/11.3G2",
        array(0,0,0), //translation
        array(5,5,5), //scale
```

```php
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        11 //CoordinateSystemID)
        );

//output the object
ArelXMLHelper::outputObject($oObject);

//image
$oObject = ArelXMLHelper::createGLUEModel3DFromMovie(
    "12",
    WWW_ROOT . "/resources/12.3G2",
    array(0,0,0), //translation
    array(5,5,5), //scale
    new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
    //rotation
    12 //CoordinateSystemID)
    );

//output the object
ArelXMLHelper::outputObject($oObject);

//output the object
ArelXMLHelper::outputObject($oObject);

//image
$oObject = ArelXMLHelper::createGLUEModel3DFromMovie(
    "13",
    WWW_ROOT . "/resources/13.3G2",
    array(0,0,0), //translation
    array(5,5,5), //scale
    new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
    //rotation
    13 //CoordinateSystemID)
    );
//output the object
ArelXMLHelper::outputObject($oObject);

//video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
    "14",
    WWW_ROOT . "/resources/14.png",
    array(0,0,0), //translation
    array(3,3,3), //scale
    new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
    //rotation
    14 //CoordinateSystemID)
    );
//output the object
ArelXMLHelper::outputObject($oObject);

//end the output
ArelXMLHelper::end();
```

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**Index.php:**

```php
<?php
/**
 * @copyright  Copyright 2012 metaio GmbH. All rights reserved.
 * @link       http://www.metaio.com
 * @author     Frank Angermann
 *
 * @abstract     Learn how to reference a movie texture (movie in
 *               liveview), alpha transparent movie and an image on
 *               different reference images.
 *
 *               Learnings:
 *               - using multiple reference images / coordinate
 *                 systems
 *               - create 3D Models from movies (3G2) - movie textures
 *                 and images(png, jpg) to display in the live view
 *               - using alpha transparent movies
 *               - using AREL JS to control the movies
 *
 **/

//if issues occur with htaccess, also the path variable can be used
//htaccess rewrite enabled:
//Callback URL: http://www.callbackURL.com
//
//htacces disabled:
//Callback URL: http://www.callbackURL.com/?path=

if(isset($_GET['path']))
      $path = $_GET['path'];
else
      $path = $_SERVER['REQUEST_URI'];

$aUrl = explode('/', $path);

//if the request if correct, return the information
if(in_array_substr('search', $aUrl))
{
      //this will be used for refreencing information in the search.php
      define('WWW_ROOT',"http://".$_SERVER['HTTP_HOST'].dirname($_SERVE
      R['SCRIPT_NAME'])); //path to online location

      //the search return needs to be provided
      include '../src/search.php';
      exit;
}

// Wrong request -> return not found
header('HTTP/1.0 404 Not found');
```

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```php
function in_array_substr($needle, $haystack)
{
    foreach($haystack as $value)
    {
        if(strpos($value, $needle) !== false)
            return true;
    }

    return false;
}
```

## Arel/Index.php:

```html
<html>
    <head>
        <meta http-equiv="Content-type" content="text/html; charset=utf-8" />
        <meta name="viewport" content="width=device-width; initial-scale=1.0; maximum-scale=1.0;">
        <script type="text/javascript" src="http://dev.junaio.com/arel/js/arel.js"></script>
        <script type="text/javascript" src="js/jquery-1.7.1.min.js"></script>
        <script type="text/javascript" src="js/arelGLUE5.js"></script>

        <style type="text/css">
            * {
                -webkit-highlight:          none;
                -webkit-touch-callout :     none;
                -webkit-user-select:        none;
            }

            body {
                margin: 0px;
                padding: 0;
                -webkit-text-size-adjust: 100%;
                background-color:transparent;
            }

        </style>

    <title>TestMovie</title>
    </head>
        <body>
        </body>
</html>
```

## arelGLUE.js:

```javascript
var timerIDTrackingInfo = undefined;

arel.sceneReady(function()
{
      //set a listener to tracking to get information about when the
      image is tracked
      arel.Events.setListener(arel.Scene, function(type,
      param){trackingHandler(type, param);});
});

function trackingHandler(type, param)
{
      //check if there is tracking information available
      if(param[0] !== undefined)
      {
            //if the pattern is found, start one of the two movies
            /with or without alpha transparency)
            if(type && type == arel.Events.Scene.ONTRACKING &&
            param[0].getState() == arel.Tracking.STATE_TRACKING)
            {
                  if(param[0].getCoordinateSystemID() == 2)
                        arel.Scene.getObject("2").startMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 4)
                        arel.Scene.getObject("4").startMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 5)
                        arel.Scene.getObject("5").startMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 10)
                        arel.Scene.getObject("10").startMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 11)
                        arel.Scene.getObject("11").startMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 12)
                        arel.Scene.getObject("12").startMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 13)
                        arel.Scene.getObject("13").startMovieTexture();
            }

            //if the pattern is lost, pause one of the two movies /with
            or without alpha transparency)
            else if(type && type == arel.Events.Scene.ONTRACKING &&
            param[0].getState() == arel.Tracking.STATE_NOTTRACKING)
            {
                  //pause the movies
                  if(param[0].getCoordinateSystemID() == 2)
                        arel.Scene.getObject("2").pauseMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 4)
                        arel.Scene.getObject("4").pauseMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 5)
                        arel.Scene.getObject("5").pauseMovieTexture();
                  else if(param[0].getCoordinateSystemID() == 10)
```

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```
                arel.Scene.getObject("10").pauseMovieTexture();
        else if(param[0].getCoordinateSystemID() == 11)
                arel.Scene.getObject("11").pauseMovieTexture();
        else if(param[0].getCoordinateSystemID() == 12)
                arel.Scene.getObject("12").pauseMovieTexture();
        else if(param[0].getCoordinateSystemID() == 13)
                arel.Scene.getObject("13").pauseMovieTexture();
        }
    }
};
```

# APPENDIX C: EXPERIMENT 1 - MYSTERY LECTURE QUESTIONNAIRE

1. <u>Planning act</u> is divided into all categories depending the <u>size of area</u> except:
   - Residential
   - State
   - County
   - Local

2. Which process is <u>not</u> necessary <u>before</u> the construction begins?
   - Complete construction drawings
   - Get approval from building inspection department
   - Choose the subcontractors to supply specialty items
   - Get building permit

3. The amount of <u>testing</u> done <u>on the site</u> depends on all the conditions except for:
   - Size and complexity of the structure
   - Type of soil encountered
   - Proximity of the proposed structure to existing buildings
   - General contractor bids

4. <u>Standard laboratory tests</u> are considered as:
   - Subsurface investigation
   - Primary investigation
   - Both of them
   - None of them

5. All the mentioned states happen during <u>Standard laboratory tests</u> except:
   - Topographic survey
   - Using a drill rig
   - Providing test boreholes
   - Using special methods to extract the required samples

6. Which one is not considered as a <u>classification for soil</u> based on <u>bearing resistance</u>:
   - Cohesionless soil
   - Cohesive soil
   - Rock
   - Clays

7. <u>Miscellaneous</u> soil is defined as:
   - Silt and clay
   - Cemented sand and gravel

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- Sand and gravel
- Rock

8. Which one is the result of <u>neglecting subsurface conditions</u> before construction begins?
    - Spidery cluster of cracks will appear
    - Cracks will creep across the walls inside the basement or garage
    - Cracks will spread throughout the foundation
    - All of them

9. The most common machine to drill the <u>test holes</u> is -----.
    - Split spoon sampler
    - Shelby tube
    - truck-mounted drilling rig
    - All of them

10. Which sampling tool has relatively <u>undisturbed</u> samples in a rounded <u>cylindrical</u> shape?
    - Split spoon sampler
    - Shelby tube
    - Augers
    - Wash borings

11. All the followings are features of <u>augers</u> except:
    - Consists of a cylinder, with cutting lips on the lower end
    - As it is turned, layers of earth are peeled off and forced up into it
    - It makes relatively undisturbed samples
    - Power augers are used for deeper depths.

12. Which one is <u>not</u> considered as a <u>rock drilling</u> type?
    - Diamond drilling
    - Cross-hole logging
    - Shot drilling
    - Churn drilling

13. Drill bit is to rotary drill as ----- is to diamond drill.
    - Diamond-studded bit
    - Chisel shaped cutting edge
    - Control means
    - Drill bit

14. Which one is <u>not</u> a step to <u>setting up a refraction seismograph</u>?
    - Laying out geophones in their approximate positions

- Planting geophones into the ground
- Keep geophones vertical on the ground
- Use a spread cable to connect geophones to the ground

15. What information about the <u>stratum</u> cannot be achieved by knowing the <u>speed of the shock wave</u>?
    - Type
    - Hardness
    - Moisture
    - Depth

16. What features does not affect the <u>Conductivity</u> and <u>resistivity of soil?</u>
    - mineral salt content of the soil
    - volume of pore spaces
    - Pore size and distribution
    - Degree of saturation

17. Which of the four following statements are advantages of geophysical instruments and which are the disadvantages? Put the corresponding numbers in table provided below.
    1. Materially reduce the amount of drilling necessary
    2. Help in the intelligent selection of drilling sites
    3. Does not eliminate the need for test boring
    4. Do not give accurate information on the bearing capacity of a soil

| advantages | disadvantages |
|---|---|
| | |
| | |

18. Which of the four following statements are advantages of test pits and which are the disadvantages? Put the corresponding numbers in table provided below.
    1. Examine the layers of earth exactly as they exist.
    2. Expensive
    3. The depth to which examination can be carried out is limited.
    4. Soil moisture conditions are evident

| advantages | disadvantages |
|---|---|
| | |
| | |

# APPENDIX D: EXPERIMENT 1 – FEEDBACK SURVEY QUESTIONNAIRE FOR TEST GROUP

**Answer the following questions. Your responses will be processed anonymously as part of an academic research project.**

How did you like using an augmented reality (AR) tool today? Did you feel any difference at all compared to a conventional lecture? Do you think AR helped you better learn the material?

Was there anything you did not like about this tool? If so, can you list a few limitations that prevented you from better using the platform?

Can you make any suggestion on how to improve or make this tool more user-friendly?

Using the following scale, describe the impact of this AR tool on your learning (circle only one).

- Perfectly designed and helpful
- Somewhat useful
- Does not affect my learning
- Distracting

On a scale of 1-5 (1=lowest, 5=highest), how do you rate your learning experience today?

On a scale of 1-5 (1=lowest, 5=highest), how likely will you recommend this tool (or a similar AR tool) to your other schoolmates and instructors to use in other courses?

**Thank you for your participation.**

# APPENDIX E: EXPERIMENT 2 – LOCATION-BASED CODE

## First three steps – index.php

```php
<?php
/**
 * @copyright  Copyright 2012 metaio GmbH. All rights reserved.
 * @link       http://www.metaio.com
 * @author     Frank Angermann
 *
 * @abstract        Learn about the different types of POIs available in
 *                  junaio. It is a different media type linked with each
 *                  POI.
 *
 *                  Learnings:
 *                          - create multiple POIs within 1 channel
 *                          - use the AREL XML Helper to create the
 *                          XML output
 *                          - link movie, sound or image with the POI
 *                          - create a custom HTML overlay to be
 *                          referenced and opened one the custom POI
 *                          is clicked
 *                          - adding parameters to the POI to be used
 *                          in AREL JS
 *
 **/

require_once '../ARELLibrary/arel_xmlhelper.class.php';

//use the Arel Helper to start the output with arel
//start output
     ArelXMLHelper::start(NULL,"/arel/index.html",ArelXMLHelper::TRACK
     ING_GPS);
//1. Sound POI
$oObject = ArelXMLHelper::createLocationBasedPOI(
          "1", //id
          "Step 1 - Description", //title
          array(28.607351, -81.197402, 0), //location
          "/resources/Step_1.png", //thumb
          "/resources/Step_1_small.png", //icon
          "Project Description", //description
          array(array("Start Movie", "movieButton",
          "http://desimal.dx.am/Junaio/step1_edited.3g2")) //buttons
     );

//output the object
ArelXMLHelper::outputObject($oObject);

//2. Image POI
$oObject = ArelXMLHelper::createLocationBasedPOI(
          "2", //id
          "Step 2 - Elements", //title
          array(28.607351, -81.197402, 0), //location
```

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```php
            "/resources/Step_2.png", //thumb
            "/resources/Step_2_small.png", //icon
            "Sorting the Elements", //description
            array(array("Start Movie", "movieButton",
            "http://desimal.dx.am/Junaio/step_2.3g2")) //buttons
    );

//output the object
ArelXMLHelper::outputObject($oObject);

//3. Video POI
$oObject = ArelXMLHelper::createLocationBasedPOI(
            "3", //id
            "Step 3 - Rules", //title
            array(28.607351, -81.197402, 0), //location
            "/resources/Step_3.png", //thumb
            "/resources/Step_3_small.png", //icon
            "Rules and Regulations", //description
            array(array("Start Movie", "movieButton",
            "http://desimal.dx.am/Junaio/step_3.3g2")) //buttons
    );

//output the object
ArelXMLHelper::outputObject($oObject);

//end the output
ArelXMLHelper::end();

?>
```

### Second three steps – index.php

```php
<?php
/**
 * @copyright  Copyright 2012 metaio GmbH. All rights reserved.
 * @link       http://www.metaio.com
 * @author     Frank Angermann
 *
 * @abstract       Learn about the different types of POIs available in
 *                 junaio. It is a different media type linked with each
 *                 POI.
 *
 *                 Learnings:
 *                         - create multiple POIs within 1 channel
 *                         - use the AREL XML Helper to create the
 *                         XML output
 *                         - link movie, sound or image with the POI
 *                         - create a custom HTML overlay to be
 *                         referenced and opened one the custom POI
 *                         is clicked
 *                         - adding parameters to the POI to be used
 *                         in AREL JS
 *
 **/

require_once '../ARELLibrary/arel_xmlhelper.class.php';

//use the Arel Helper to start the output with arel
//start output
    ArelXMLHelper::start(NULL,"/arel/index.html",ArelXMLHelper::TRACK
    ING_GPS);
//1. Sound POI
$oObject = ArelXMLHelper::createLocationBasedPOI(
        "1", //id
        "Step 4 - Factors", //title
        array(28.607351, -81.197402, 0), //location
        "/resources/Step_1.png", //thumb
        "/resources/Step_1_small.png", //icon
        "Assessment Factors and Goals", //description
        array(array("Start Movie", "movieButton",
        "http://desimal.dx.am/Junaio/step_4.3g2")) //buttons
    );

//output the object
ArelXMLHelper::outputObject($oObject);

//2. Image POI
$oObject = ArelXMLHelper::createLocationBasedPOI(
        "2", //id
        "Step 5 - Materials", //title
        array(28.607351, -81.197402, 0), //location
```

```php
            "/resources/Step_2.png", //thumb
            "/resources/Step_2_small.png", //icon
            "Material Information", //description
            array(array("Start Movie", "movieButton",
            "http://desimal.dx.am/Junaio/step_5.3g2")) //buttons
        );

//output the object
ArelXMLHelper::outputObject($oObject);

//3. Video POI
$oObject = ArelXMLHelper::createLocationBasedPOI(
            "3", //id
            "Step 6 - Assessment tables", //title
            array(28.607351, -81.197402, 0), //location
            "/resources/Step_3.png", //thumb
            "/resources/Step_3_small.png", //icon
            "Filling Out Assessment Tables", //description
            array(array("Start Movie", "movieButton",
            "http://pegasus.cc.ucf.edu/~abehzada/test/step6_edited.3g2"
            )) //buttons
        );

//output the object
ArelXMLHelper::outputObject($oObject);

//end the output
ArelXMLHelper::end();

?>
```

# APPENDIX F: EXPERIMENT 2 – IMAGE-BASED CODE

**index.php**

```php
<?php

/**
 * @copyright  Copyright 2012 metaio GmbH. All rights reserved.
 * @link       http://www.metaio.com
 * @author     Frank Angermann
**/

require_once '../library/arel_xmlhelper.class.php';

/**
 * When the channel is being viewed, a poi request will be sent
 * $_GET['l']...(optional) Position of the user when requesting poi
 search information
 * $_GET['o']...(optional) Orientation of the user when requesting poi
 search information
 * $_GET['p']...(optional) perimeter of the data requested in meters.
 * $_GET['uid']... Unique user identifier
 * $_GET['m']... (optional) limit of to be returned values
 * $_GET['page']...page number of result. e.g. m = 10: page 1: 1-10;
page 2: 11-20, e.g.
 **/

//use the Arel Helper to start the output with arel

//start output
    ArelXMLHelper::start(NULL, WWW_ROOT . "/arel/index.php", WWW_ROOT
    . "/resources/tracking.zip");
//video
$oObject = ArelXMLHelper::createGLUEModel3D(
    "movie",    //ID
    WWW_ROOT."/resources/one.md2", //model
    WWW_ROOT."/resources/steel.png", //texture
    array(0,0,0), //translation
    array(5,5,5), //scale
    ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,180,0)),
    //rotation
    1 //CoordinateSystemID
    );

//return the model
ArelXMLHelper::outputObject($oObject);
//video
$oObject = ArelXMLHelper::createGLUEModel3D(
    "image",    //ID
    WWW_ROOT."/resources/two.md2", //model
    WWW_ROOT."/resources/concrete.png", //texture
    array(0,0,0), //translation
    array(5,5,5), //scale
```

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```php
        new ArelRotation(ArelRotation::ROTATION_EULERDEG,
        array(0,180,0)), //rotation
        2 //CoordinateSystemID
        );

//return the model
ArelXMLHelper::outputObject($oObject);

//video
$oObject = ArelXMLHelper::createGLUEModel3D(
        "movieTransparent",      //ID
        WWW_ROOT."/resources/three.md2", //model
        WWW_ROOT."/resources/steel.png", //texture
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG,
        array(0,180,0)), //rotation
        3 //CoordinateSystemID
        );

//return the model
ArelXMLHelper::outputObject($oObject);

//video
$oObject = ArelXMLHelper::createGLUEModel3D(
        "hello",     //ID
        WWW_ROOT."/resources/four.md2", //model
        WWW_ROOT."/resources/concrete.png", //texture
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG,
        array(0,180,0)), //rotation
        4 //CoordinateSystemID
        );

//return the model
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "my", //ID
        WWW_ROOT . "/resources/beam1.png",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        5 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
```

```php
        "name",     //ID
        WWW_ROOT . "/resources/beam2.png",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        6 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "is", //ID
        WWW_ROOT . "/resources/beam3.png",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        7 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "arezoo",    //ID
        WWW_ROOT . "/resources/beam4.png",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        8 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "shirazi",  //ID
        WWW_ROOT . "/resources/jun1.png",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        9 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "I",  //ID
```

```php
      WWW_ROOT . "/resources/jun2.png",
      array(0,0,0), //translation
      array(5,5,5), //scale
      new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
      //rotation
      10 //CoordinateSystemID)
      );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
      "am", //ID
      WWW_ROOT . "/resources/jun3.png",
      array(0,0,0), //translation
      array(5,5,5), //scale
      new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
      //rotation
      11 //CoordinateSystemID)
      );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
      "twenty",   //ID
      WWW_ROOT . "/resources/jun4.png",
      array(0,0,0), //translation
      array(5,5,5), //scale
      ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
      //rotation
      12 //CoordinateSystemID)
      );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
      "three",    //ID
      WWW_ROOT . "/resources/jun5.png",
      array(0,0,0), //translation
      array(5,5,5), //scale
      new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
      //rotation
      13 //CoordinateSystemID)
      );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
      "years",    //ID
      WWW_ROOT . "/resources/jun6.png",
```

```php
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        14 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//transparent video
$oObject = ArelXMLHelper::createGLUEModel3DFromImage(
        "old",       //ID
        WWW_ROOT . "/resources/material.png",
        array(0,0,0), //translation
        array(5,5,5), //scale
        new ArelRotation(ArelRotation::ROTATION_EULERDEG, array(0,0,0)),
        //rotation
        15 //CoordinateSystemID)
        );
//output the object
ArelXMLHelper::outputObject($oObject);

//end the output
ArelXMLHelper::end();
```

# APPENDIX G: NASA-TLX QUESTIONNAIRE

# User ID: ……

For each of the pairs listed below, circle the scale title that represents the more important contributor to workload in the display.

Mental Demand      or      Physical Demand

Mental Demand      or      Temporal Demand

Mental Demand      or      Own Performance

Mental Demand      or      Effort

Mental Demand      or      Frustration

Physical Demand      or      Temporal Demand

Physical Demand      or      Own Performance

Physical Demand      or      Effort

Physical Demand      or      Frustration

Temporal Demand      or      Own Performance

Temporal Demand      or      Frustration

Temporal Demand      or      Effort

Own Performance      or      Frustration

Own Performance      or      Effort

Frustration      or      Effort

# User ID: ......

Please place an "X" along each scale at the point that best indicates your experience with the display configuration.

**Mental Demand:** How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

**Physical Demand:** How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

**Temporal Demand:** How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

**Performance:** How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

**Effort:** How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

**Frustration:** How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low |___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___|___| High

# APPENDIX H: EXPERIMENT 2 – FEEDBACK SURVEY QUESTIONNAIRE FOR CONTROL GROUP

# User ID: ……

**Now that you have completed this experiment, answer the following questions. Your responses will be processed anonymously as part of an academic research project (Circle only one).**

How clear were the manual instructions to use?

- Very clear
- Clear
- Somewhat clear
- Not clear

Please rate the ease of use of the manual in extracting required information.

- Very easy
- Required trial and error
- Difficult
- Never worked

On a scale of 0-100, how much of your time was spent on communicating with your teammates?

On a scale of 0-100, rate the level of "interactivity" of the experiment.

If you were doing this experiment by yourself (alone) but were given 3 hours of time instead, what percentage of the work you achieved today with the rest of your group, do you think you would have achieved? (Please rate on a scale of 0-100)

Please rate your overall assessment of the experiment on a scale of 1-5 (1=lowest, 5=highest).

**Thank you for your participation.**

# APPENDIX I: EXPERIMENT 2 – FEEDBACK SURVEY QUESTIONNAIRE FOR TEST GROUP

# User ID: ……

**Answer the following questions according the experiment you just participate. Your responses will be processed anonymously as part of an academic research project (Give only one answer please).**

How effective were the instructions delivered through the AR application in helping you obtain necessary information during your design experiment?

- Very effective
- Effective
- Somewhat effective
- Not effective

Please rate how clear and easy to use was this AR technology in extracting required information.

- Very easy
- Required trial and error
- Difficult
- Never worked

Using the following scale, describe the impact of this AR tool on your learning.

- Perfectly designed and helpful
- Somewhat useful
- Does not affect my learning
- Distracting

I believe putting the application into practice is feasible in the university context.

- Agree
- Disagree

I believe the AR application is interactive.

- Agree
- Disagree

On a scale of 0-100, how much of your time was spent on communicating with your teammates?

If you were doing this experiment by yourself (alone) but were given 3 hours of time instead, what percentage of the work you achieved today with the rest of your group, do you think you would have achieved? (Please rate on a scale of 0-100)

Please rank the effectiveness of the location-based AR virtual instructor on a scale of 1-5 (1=lowest, 5=highest)

Please rank the overall AR information delivery platform on a scale of 1-5 (1=lowest, 5=highest)

On a scale of 1-5 (1=lowest, 5=highest), how likely is it that you recommend this tool (or a similar AR tool) to your other schoolmates and instructors for use in other courses?

Please rate your overall assessment of the experiment on a scale of 1-5 (1=lowest, 5=highest).

**Thank you for your participation.**

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