Using Augmented Reality to Enhance Construction Management Educational Experiences

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Abstract

It is essential for the future industry workforce to fully develop their learning abilities to help them effectively solve construction problems. The ability of Construction Management (CM) students to solve problems is adversely impacted by the lack of experience that can be derived from exposure to construction processes on the job-site. The result is a lack of understanding of the dynamic complex spatial constraints (e.g., how construction products are related to one another in particular contextual space) and the temporal constraints (e.g., the dependencies for coordinating subcontractors' processes). The full understanding of the spatio-temporal constraint problems that pervade projects during the construction phase can significantly enable students to improve productivity levels.

This study uses Augmented Reality Technology (ART) and a layer of artificial visualizations to simulate the environmental context and spatio-temporal constraints. The superimposition of images serves as an instructional mechanism to virtually incorporate jobsite experiences. The assumption is that the enhancement of spatio-temporal constraints enables learners to visualize context and hidden processes. Therefore, a significant improvement of the perception of the reality is expected through the combination of the learners' ability to understand the complexity of construction products (e.g., assemblies) and associated jobsite processes by using the real environment augmented with computer-generated information layers.

Keywords: Augmented Reality, Education, Construction Assemblies, Construction Management; spatio-temporal constraints

1 Introduction

The future of the construction industry depends on the cabilities of new employees, who often get their start studying at colleges and universities around the world. It is vital for them to enter the workforce with the ability to solve the complex problems inherent in the construction process. Unfortunately, lack of exposure to such processes during their education makes it difficult for students to fully develop an understanding of the spatial (e.g., the relation of tasks and processes to one another on site) and temporal constraints (e.g. schedule or procedural dependencies between various tasks and trades) which exist during the construction process. Often, teaching techniques seek to remedy this lack of exposure through site visits and in-class media presentations. However, advancements in Augmented Reality Technology (ART) have allowed for the development and evaluation of new methods of providing information to students.

This study involves the assessment of the spatio-temporal capabilities, as they relate to the construction process, of a group of students enrolled in an undergraduate construction management program. A sample project was extensively documented throughout the construction phase and the subsequent data was utilized to develop the augmented video. The research team worked to identify specific elements of the masonry assembly that were lacking environmental context, thus restricting the students' ability to fully develop an understanding of the spatio-temporal constraints involved. In this regard, this study postulated that the combination of visually documented jobsite experiences superimposed with virtual enhancements will enable students to gain a more thorough understanding of the documented construction process. ART was employed in the development of a video, superimposed with virtual building elements, demonstrating the complex process of masonry construction.

Since the implementation of new technologies tend to be an appealing proposition for many members of the academic community, it is vital to gain an understanding of the impact that such technology may have on student learning. This study aims to understand how the use of ART, as a mechanism to simulate the environmental context of construction processes, can enhance construction management educational experiences. Thus, providing a new instruction tool for educators to improve the contextual learning and experience of their students as they prepare to enter the industry workforce.

1.1 Problem statement

Students studying construction management today often lack experience related to the complexity of many construction processes. Typical field trips conducted during their education provide some insight, but it is difficult to get students on site when specific processes are taking place which relate to their on-going course of study. They are exposed to general construction procedures in an ad-hoc manner, but often the idiosyncrasies of specific tasks or assemblies are not fully captured. This partial exposure to complete processes and procedures leaves students with a limited understanding of the spatial and temporal constraints which exist on a construction jobsite. This lack of experience and understanding leaves the students ill prepared to enter the workforce, and with stunted abilities to show immediate productivity as members of their respective companies.

1.2 Research goals and hypotheses

The primary objective of this study is to determine whether the use of augmented reality can enhance the educational experience of construction management students. Through the establishment of a test case and use of visual documentation, layered with virtual visualization augmented reality technologies, learning assessments will be conducted to determine the students' understanding of the spatio-temporal constraints which exist within the given test case. An initial baseline of understanding is established to determine how effective the existing lecture and test method of teaching is in providing students with the necessary information about a given construction subject area. Subsequently, augmented reality visualizations are introduced to simulate additional context and help the students increase their understanding of the construction processes. These visualizations will be achieved through the use of augmented reality technology (ART) and provided to the students in a user friendly video format. Finally, the hypotheses that the use of augmented reality will enhance the students understanding of the spatio-temporal constraints which pervade construction projects was tested.

2 Augmented reality in the construction industry

Augmented reality is the superimposition of computer generated digital information over real world views (Rankohi and Waugh 2013). The study of the applications for augmented reality has spanned many industries and has continued to evolve. The architecture, construction and engineering (AEC) industry has begun to explore applications for augmented reality and many researchers are completing work in this regard. Some of the areas which researchers are employing augmented reality include; as-planned to as-built progress monitoring, training, dynamic site visualization, construction defect detection and integrating with various building information modelling (BIM) workflows (Rankohi and Waugh 2013). According to a review of augmented reality literature by Rankohi and Waugh (2013) there remains a lot of work to be done and the full potential for augmented reality applications has yet to be achieved.

The primary research areas for augmented reality in the AEC industries have focused on the use of the technology in the field. One such example was the use of augmented reality for steel column inspections completed by Shin and Dunston (2009) in their study to detect the accuracy of anchor bolt positions and steel column plumbness (Dunston and Shin 2009). Dunston and Shin (2009) concluded that the use of their augmented reality setup showed promise for increased productivity since the graduate students who had never before used augmented reality technology were able to complete the inspections more effectively. That work demonstrated the ability of students to use a new technology effectively with little training, however, little follow on research can be found regarding the use of augmented reality for AEC related educational experiences.

Rankohi and Waugh (2013) reported that 8% of the articles related to augmented reality targeting students as well as their experiences and that 5%, or 8 of the 133 articles reviewed, were focused on the education or training application areas within the AEC industry. Augmented reality is an emerging technology in the AEC industry, which demonstrates promise for a variety of applications. The application of augmented reality for educational purposes has not been as explored as much as other use cases. Augmented reality technology has the potential to be intertwined through the entirety of the construction process and some recommend that AEC members monitor this area of study to stay up to date, due to its rapid evolvement (Rankohi and Waugh2009). This recommendation should be extended to not only those in the workforce, but also to those, students, training to enter the workforce.

3 Augmented reality test case

3.1 Selected sample project

For the purposes of this study the research team collaborated with a local contractor to document the entirety of a construction project and the processes involved. Construction of the sample project began in the fall of 2013 and the researchers visited the jobsite daily throughout construction phase to capture image and video data. Standard imaging techniques as well as an unmanned aircraft system (UAS), were used to gather data from multiple vantage points. The visual data collected was primarily intended for use in this study, however it was also shared with the contractor for their use as part of their project documentation. All of the data captured was stored on a secured computer system and was organized by date of capture and construction category for ease of access as the study progressed.

The project itself was a multi-story academic classroom and office building being constructed for the University of Florida (UF). The construction site was located on the historic area of the UF campus requiring special consideration for design and long lasting construction techniques. The general construction style was a steel structural frame enclosed with masonry exterior walls faced with a brick veneer. In addition, the building had advanced information technology and HVAC systems which could be documented throughout the installation phases. Collaboration with the contractor fostered a relationship which, coupled with the close proximity of the project to the researchers home building, allowed for exceptional site access. Additionally, the contractor worked with the researchers to identify key installation dates and project milestones to document. This project proved to be ideal for this study due to the breadth of information which could be gathered through the documentation of the entire construction process.

The team worked to document site activity and construction processes on a daily basis, spanning from foundation excavation through final building inspections. Still images as well as video were taken in order to provide a variety of media platforms to work from as this study progressed. Figure 1 is an example of the project documentation and depicts the construction project as of August of 2014. Due to the design and selected building systems, a wide range of construction techniques were used including; steel erection, masonry work, metal stud framing, clay tile roofing, stone parapet installation, chilled beam air conditioning system installation, and fireproofing. The installation of roll on water proofing was captured in Figure 2. The range of systems afforded the research team the opportunity to document a variety of installation techniques capturing the means and methods involved which were a crucial consideration for this study.

3.1.1 Masonry construction

The exterior masonry system was selected as the primary assembly to focus on and was utilized for the remainder of the study. The masonry system included the CMU backing wall, waterproofing, insulation, brick veneer and all other associated masonry wall accessories (e.g. brick wall ties). Masonry quantity takeoff and cost estimating often provides a challenge for unexperienced students due to the idiosyncrasies of the assembly process which may be unknown to them.

Figure 1 Overall construction progress image as of August 2014 captured via an unmanned aircraft

Figure 2 Example of project documentation, waterproofing installation on the exterior CMU

4 Study participants

The data analyzed in this research is based on a sampling of students currently enrolled in the Construction Management program at the M.E. Rinker, Sr. School of Construction Management at the University of Florida. The research was performed with students in their second semester of their junior year in the program. The AR study was developed for implementation in the first of two estimating classes in the program. The Estimating 1 class is the first class that exposes the students to the construction estimating process. The student learning objectives for this course are:

1. Understand the significance of estimating to the construction industry and identify the duties, responsibilities, and risks associated with construction estimating.
2. Recognize different types of estimates and their uses.
3. Read and interpret the drawings and specifications.
4. Perform quantity takeoffs based on the drawings and specifications and
5. Generate detailed estimates.
6. Use computers to assist in quantity takeoffs

Prior to the Estimating 1 course students take a course that exposes them to various construction techniques. This is accomplished through reading and classwork along with visits to jobsites and material fabricators. Additionally, subcontractors present demonstrations of the various trades. The Estimating 1 course builds on the knowledge the students gain about construction techniques teaching them how to quantify the cost items necessary to prepare an accurate cost estimate. The course focus is on identifying all items in a construction process that have cost implications that are either indicated or implied in the Construction Documents. This requires the Estimating 1 instructor to review techniques already presented to students in prior courses and build on that knowledge.

The difficulty in teaching cost item quantification is in helping the students to understand those cost items that are not directly indicated on the drawings or in the specifications but are a necessary items to performing these work items. The knowledge of these ancillary cost items is typically learned through experience and has to be conveyed to the students as part of a complete estimating course. The focus of the AR research presented in this paper is to AR to visually aid the teaching of these construction processes in a classroom setting without the inconvenience or unavailability of visiting a construction site.

The students involved in this research were between the ages of 20 and 26 years old with a 87% male and 13% female distribution. Of all students, 97% were US residents and all but one student were pursuing a B.S. degree in Construction Management. The one student was enrolled in a Quantity Surveying program in an Australian university. None of the students had completed a previous

Bachelor's degree. The student's experience in the construction industry was divided with 82% having prior work experience in some capacity as an intern in the construction industry and 18% having no prior intern experience. Seventy six percent of students had visited a jobsite outside of class site visits with 24% having never visited a jobsite. All students stated that they had at least some level of computer knowledge and literacy. The average of all student's self-rating of familiarity with information technology was 3.45 out of 5.

5 Experimental considerations

5.1 Augmentation procedure

In order to augment a virtual model onto a construction site video a variety of software packages are used to achieve a satisfactory result. The entire collection of site images and videos was reviewed and some were selected to receive the augmentation. This selection was based primarily on content and then was screened for adequate quality and smooth camera positioning. A camera tracking software was utilized first to process the video, defining the camera path and defining object locations within the construction site. The camera path script data generated was then taken into 3D modeling software to begin the process of combining the visual media and virtual objects. The desired virtual model can be placed in the appropriate location due to the series of object markers, defined by the camera tracking software, which can be assigned to various elements found within the shot. Thus, the desired 3D model was located within the defined object markers and visualized from the appropriate camera path and angle. For the purposes of this study, video editing software was then used to combine multiple videos and images depicting the entire masonry assembly process, with selected augmentation. Figure 3 shows the outcome of the layering of virtual and real-world information layers. The virtual model, of the portion of the building that was used in the student evaluations, is shown in its final form over the as-built structure on the jobsite. The BIM model transitioned through varied levels of opacity to allow the students to scrub through the video and view it as they saw fit. Figures 4 and 5 show augmentation conducted of the steel erection and roof construction process respectively. In both cases, the virtual models were superimposed on media of as-built site conditions documented by the research team.

The order of steel erection is shown in Figure 4 which allowed for the visual and spatial

Figure 3 Completed BIM model augmentation over on-site construction progress documentation

understanding of the process. Similarly, the process of installing the water proofing membrane on a roof was augmented to help foster the understanding of necessary overlap which allows the students to infer that a higher quantity of material than square foot calculations alone may suggest would be needed in the actual construction process. All of these augmentation examples were developed using the prescribed process and were reviewed by the project team to determine the methods which may work most favorably for the remainder of the study

5.2 Masonry component augmentation

The research team identified specific elements of the masonry assembly which students tended to have a difficult time of identifying based on the knowledge of the estimating class faculty. Masonry wall ties, and flashing were selected as the assembly elements which should be the focus of the augmented reality development. These elements were enhanced through the augmentation of BIM components into the real world visual documentation. No words or sounds were used in conjunction with the visualizations, in order to eliminate any undue influence on the students.

A portion of a brick masonry tie embedded in a CMU backing wall is shown in Figure 6. The virtual model of the tie is visually removed from its position in the wall and enlarged to allow for an understanding of how it remains in place. Additionally, Figure 7 shows the augmentation related to the location and placing of copper flashing within the brick veneer. Figure 7 is a still image capture of a longer video sequence which shows the location and various stages of flashing installation. Those examples were part of the augmentations which were superimposed over real-world visuals capturing the entirety of the masonry wall installation process.

Figure 4 Augmentation of steel structure over existing as-built site conditions

Figure 5 Water barrier installation augmentation displaying proper and as-built overlap conditions

Upon the completion of augmentation the developed video was packaged as a standard video file and hosted on a secure server, which the students were provided access to as needed during the appropriate phases of the study. The completed masonry construction video with augmentation was 2 minutes and 49 seconds in length. During the assessments, students were permitted to view the video and scrub through it as they saw fit, with no involvement from the proctors, other than

Figure 6 Augmentation of masonry wall ties in CMU backing wall

Figure 7 Copper flashing noted in video of brick veneer installation process

providing them access to the video. The selected augmentations and video were reviewed by the research team to ensure the contextual accuracy of all components.

6 Experimental procedure

In order to assess the effectiveness of augmented reality in enhancing educational experiences, a study was conducted involving students enrolled in an Estimating 1 course at the University of Florida's M.E. Rinker, Sr. School of Construction Management. All participation was voluntary and participants were informed of their rights based on the regulations of the University of Florida Institutional Review Board. Consent forms were signed by the participants following the explanation of the purpose of the study, as well as what would be required during their participation. The standard lecture regarding masonry construction estimating and the augmented reality enhanced video were used in various combinations in order to attain an effective means for data analysis upon the conclusion of the study.

6.1 Pilot study

In the fall of 2014 the research team began a pilot study in order to review the proposed experimental procedure and receive feedback prior to deploying the study full scale in the spring. These initial participants in the study and those who utilized the augmented reality enhanced video were provided a survey regarding the usability of the video. Upon completion of the study there were no problems were reported with the proposed procedure or with the usability of the video. In this regard, the results from the pilot study were included with the results from the full study for data analysis following the conclusion of the study in the spring semester of 2015.

6.2 Procedure

The study was conducted in two phases with the participants being split into three testing groups. The two phases were developed to accurately assess the participants' base knowledge and then assess the impact of the various instructional tools used. Each group was randomly selected, through the use of a random number generator, and provided with varied combinations of information regarding masonry wall assemblies. Upon the development of the three test groups each participant was provided a number and their name was not included in any documents or results seen by the research team. The random number generated during the grouping process became the participants' identifier throughout the study, which could be compared to a master list in the event that a name was needed. Furthermore, the research team members completing the data analysis were not involved in the proctoring of the experiment and had no access to the participants.

The information available to each of the three groups, Groups A, B and C, is outlined in Table 1. Group A was the control group and attended the standard masonry lecture but was not permitted to view or access the masonry wall assembly video. Group B was permitted to attend the standard lecture and was then given access to the masonry wall assembly AR video containing the augmentations. Group C was not permitted to attend the standard lecture and was only given access to the masonry wall assembly AR video. In addition to this information, each participant was provided with identical document sets for each of the two phases of the experiment.

Table 1: Group designations and associated information streams

Group A	Group B	Group C

Lecture Only (Control)	Lecture and AR Video	AR Video Only

The participants attended class three times a week and the study was completed over the span of two class periods. Phase one was completed during their Monday class and phase two was completed during their Friday class. In the first class participants were asked to complete the first phase of the study. During that part of the study, the participants were provided a simple parametric 3D view of the sample project and had no additional information other than any knowledge they may have attained through their own experiences. The students answered qualitative questions regarding material components, task identification and task sequencing related to masonry wall assemblies. This portion of the study allowed for the establishment of a baseline of knowledge in order to effectively determine the change in each participants' knowledge and spatio-temporal understanding of the masonry construction process.

The second phase of this study took place on a separate day, with the assigned groups receiving the traditional masonry estimating lecture in the intervening class time. During that phase the participants were asked to complete an estimating assignment, as well as the qualitative questions regarding material components, task identification and task sequencing of the masonry wall assembly. All participants were provided with a set of construction drawings for the portion of the test case building they would be working with to complete the assigned tasks. These drawings included plans, sections and 3D parametric views of the building. For the integrity of the study the three groups were separated and those in groups B and group C were brought to a computer lab where they were provided access to the augmented reality enhanced masonry video. Access to the video was provided on individual computer terminals while they completed the assignment. In addition, the participants were not permitted to discuss their work with one another or ask questions of the proctor.

All documents and work associated with the participants' answers to the questions were collected and filed based on their assigned identification number. This information was then entered into a database for analysis. Documentation, both physical and digital, was kept in a secured location and on secured servers. Finally, those students in group C who were not permitted to attend the standard masonry lecture at the time it was given, were provided with a makeup lecture in order to ensure that they were not deprived of any information in the pursuit of their studies.

7 Results

There were no significant differences between the groups' overall grades for the estimating assignment. That can be attributed to the fact that the video did not include extensive augmentations for all elements in the brick veneer wall. In order to examine the true effects of the video, more in-depth data analyses had to be conducted.

Table 2 shows all the elements in the brick veneer wall that were introduced in the estimating class as well as the number of students that listed each item in their answers. The number of observations for each element from each group was then converted to a sample proportion. Comparing the different groups' sample proportions for each element would indicate if there are any significant differences between them. The pre-test sample proportions will be compared to establish all groups that have a comparable base line, which would allow for more accurate post-test comparisons.

The elements that were highlighted as an augmentation in the video were brick ties and flashing. All the other elements were visible in the video but not highlighted. Comparing the sample proportions was conducted using Minitab (2010) statistical software with the null hypothesis postulating that there is no difference between the sample proportions. Equations (1) and (2) show the null and alternate hypotheses used in the 95% confidence level analyses.

Table 2 number of observations and sample proportions

Q1. What are the main elements of the brick veneer wall assembly shown?	Group A Observations (Lecture Only)				Group B Observations (Lecture and Video)				Group C Observations (Video Only)			
	n = 13				n = 13				n = 11			
	Pre-Test	$\hat{p}$	Post-Test	$\hat{p}$	Pre-Test	$\hat{p}$	Post-Test	$\hat{p}$	Pre-Test	$\hat{p}$	Post-Test	$\hat{p}$
CMU	9	0.69	10	0.77	6	0.46	11	0.85	5	0.45	8	0.73
Waterproofing	6	0.46	9	0.69	7	0.54	10	0.77	3	0.27	9	0.82
Insulation	4	0.31	10	0.77	2	0.15	6	0.46	3	0.27	3	0.27
Bricks	11	0.85	10	0.77	10	0.77	12	0.92	10	0.91	10	0.91
Mortar	9	0.69	6	0.46	9	0.69	8	0.62	8	0.73	7	0.64
Rebar	2	0.15	4	0.31	2	0.15	3	0.23	2	0.18	7	0.64
Brick Ties	5	0.38	4	0.31	8	0.62	12	0.92	6	0.55	8	0.73
Flashing	2	0.15	5	0.38	5	0.38	9	0.69	1	0.09	1	0.09
Stone Cap	1	0.08	4	0.31	1	0.08	4	0.31	2	0.18	3	0.27

$$H_0:\ \hat{p}_1 - \hat{p}_2 = 0 \qquad (1)$$

$$H_a:\ \hat{p}_1 - \hat{p}_2 < 0 \qquad (2)$$

The collected data showed with 95% confidence that there were no significant differences between the control group and the experimental group's answers in regard to the non-highlighted elements (p-value > 0.05). On the other hand, the highlighted elements did show significant differences as described in details below. Table 3 provides the results of the pre-test and post-test null hypothesis testing completed for both the flashing and brick tie data sets.

Table 3 Minitab output for tests for difference = 0 (vs < 0)

Item	Difference Test	Phase	p-value
Flashing	$\hat{p}_A - \hat{p}_B$	Pre-test	0.085
	$\hat{p}_A - \hat{p}_B$	Post-test	0.049
	$\hat{p}_A - \hat{p}_C$	Pre-test	0.638
	$\hat{p}_A - \hat{p}_C$	Post-test	0.966
Brick Ties	$\hat{p}_A - \hat{p}_B$	Pre-test	0.113
	$\hat{p}_A - \hat{p}_B$	Post-test	0.000
	$\hat{p}_A - \hat{p}_C$	Pre-test	0.213
	$\hat{p}_A - \hat{p}_C$	Post-test	0.012

For the "Flashing" item, the null hypothesis for the pre-test sample proportions between groups A and B could not be rejected (p-value = 0.085), which means that the two groups had similar proportions prior to the experiment. However, for the post-test sample proportions, the null hypothesis was rejected (p-value = 0.049), which indicates that groups A and B have significantly different proportions. This was not the case for the comparison between groups A and C where the sample proportions did not show any significant differences in the pre or post-tests (p-value > 0.1).

Additionally, for the "Brick Ties" item, the post-test sample proportions were found to be significantly different between groups A and B (p-value < 0.001) as opposed to the pre-test p-value of 0.113. Similar results were obtained for the comparison between groups A and C with p-values of 0.213 for the pre-test and 0.012 for the post-test. This means the item "Brick Ties" was detected significantly more times by the participants who watched the augmentation video than by those participants who only received the standard lecture.

8 Conclusions

The implementation of augmented reality technology (ART) for construction management applications is rapidly evolving and being considered in new ways There is still a lot of work to be done before such technology finds main stream use to enhance the experiences of construction management students. This research is a first step in determining the effectiveness of ART for enhancing construction education experiences and discovering how to optimize its use. The ability to further develop students' spatio-temporal understanding of the complex problems which pervade the construction industry is a crucial part of preparing them to enter the workforce.

The results of this study show that the augmentation video increased students' understanding of the brick veneer wall elements. The group that had access to the lecture and video had the highest benefits. That means the augmentation video helped stress the concepts and elements introduced in class. The video helped those students visualize and be able to remember the "brick ties" and "flashing" elements of the wall more clearly. In addition, students that had access to the video without the lecture remembered the brick ties more than the students in the lecture only. However, those students did not know the correct terminology since it was not mentioned in the video. Therefore, the best outcome can be achieved by exposing the students to the augmentation video as a supplement to the class instead of a replacement.

Moreover, the level of augmentation affected the level of understanding and remembering for students. The results indicated that the students' ability to recognize the "brick ties" element was impacted more by the augmentation than their recognition of the "flashing" element (lower p-value). That can be attributed to the fact that the brick ties had higher level of augmentation in the video whereas the flashing was only highlighted. Although this study only discussed the effects of understanding the elements in a brick veneer wall, the same concept can be applied to any system in the construction industry. In future work different assemblies should be used to conduct similar tests and further discern the most effective use for ART. Continued and adaptive research regarding the impacts of ART on construction management education will be crucial as the technology continues to evolve and grow in the coming years.

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