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USE OF AUGMENTED REALITY TO ENHANCE COMPREHENSION OF STEEL STRUCTURE CONSTRUCTION

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Abstract: The future of the construction industry is highly dependent on the competence of new employees. Therefore, it is very important for new employees to enter the industry with the abilities required to resolve the intricate complications inherent in the construction process. However, inadequate exposure of Construction Management students to in-situ construction processes and procedures can be detrimental to their early success and ability to effectively solve problems. In this regard, students often lack comprehension of the complex spatial and temporal constraints which exist during the construction process, thus limiting their productivity. The goal of this study is to determine the value of advanced construction technologies for improving spatial-temporal comprehension of construction processes in construction management students.

This study uses Augmented Reality (AR) and a layer of computer visualizations to simulate and enhance the environmental context and spatio-temporal constraints of steel structure erection to determine if learners are able to better comprehend the elements and hidden processes which exist during construction. The positive effects of AR are demonstrated in this study, warranting future research and consideration for construction management education.

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

1 INTRODUCTION

It is very important for new employees to enter the construction industry with the ability to solve intricate and complex situations inherent in the construction processes. The future of the construction industry is highly dependent on the competence of these new employees as they begin their professional careers. However, the prevalent situation in higher education leads to an inadequate exposure of students to many construction processes and procedures. This results in a comprehension deficiency of the spatial and temporal constraints which exist during construction. Advanced teaching techniques that can provide greater insight to students are needed to enhance the educational experience of construction management students. This study uses Augmented Reality (AR) combined with a layer of artificial visualizations to simulate the environmental context and spatio-temporal constraints which exist during steel construction.

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As this technology continues to gain popularity it is crucial to study and understand its ability to enhance educational experiences. This study aims to assess the impact of AR, as a mechanism to simulate the environmental context of construction processes, on construction management educational experiences, and evaluates the impact of AR on learning outcomes in construction management education. The results of this study provide a basis of understanding for educators seeking to integrate a new instructional tool for the improvement of their students' educational experiences and comprehension of the construction industry.

1.1 Problem Statement

Construction management students today are inadequately exposed to many construction processes and procedures, and therefore lack experience related to the multitude of complex processes which exist in construction. Sole dependence on traditional teaching techniques, such as field trips, can fail to deliver the contextual details required to fully grasp the complex nature of every aspect of a construction project. Furthermore, this can lead to a comprehension deficiency of the spatial and temporal constraints which exist during construction. The resulting lack of experience and understanding renders the students inadequately equipped for entry into the workforce. The scope of this study focuses on improving the spatial and temporal skills of construction management students through the use of AR, with efforts directed at meeting the needs of industry.

1.2 Research Goals and Hypotheses

The primary objective of this research is to determine whether the use of AR can enhance the educational experience of construction management students and improve their spatio-temporal comprehension of specific construction processes. This study builds upon previously published work (Blinn et al. 2016, Blinn et al. 2015) and expands the research area to structural steel erection and assemblies. In this regard, identical methodologies were utilized for the development of AR-enabled content and data collection. The hypotheses that the use of augmented reality will enhance the students' comprehension of the spatio-temporal constraints prevalent in steel structure construction projects was tested. 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.

2 AUGMENTED REALITY IN THE CONSTRUCTION INDUSTRY

AR is a discipline that merges the real-world, computer generated (virtual) world and computer-generated data (Izkara et al. 2007). The study of the applications for AR has spanned across many industries, including the construction industry, and continues to evolve. However, the full potentials for augmented reality applications have yet to be achieved. AR is an emerging technology in the architecture, construction, engineering and operations (AECO) industry and it demonstrates promise for a variety of applications. The AECO industry has begun to explore applications for AR in the areas of as-planned to as-built progress monitoring, training, dynamic site visualization, construction defect detection and integration with various building information modeling (BIM) workflows (Rankohi and Waugh 2013).

The majority of research for augmented reality in AEC industry has focused on the use of AR in the field. A review of AR based research completed by Rankohi and Waugh (2013) found that 5% of research conducted focused on education and training in the AECO industry. However, applications of AR in the field can be extended to educate and train students in preparation for joining the workforce. A case study that highlights this was the use of a building information model (BIM) and mobile augmented reality (MAR) device to provide virtual data and information about actual building components and systems to facility managers on their mobile devices (Gheisari et al. 2014). A similar design can be employed as an educational tool to enable the improvement of learners' spatial-temporal skills by tailoring the augmented experiences to what is being taught in the classroom, thereby providing a more effective learning experience.

3 AUGMENTED REALITY TEST CASE

The methodology used for the development of the AR-enabled content and data collection for the structural steel construction is the same as previously published work (Blinn et al. 2016, Blinn et al. 2015), upon which this study is built upon. In order to obtain the necessary data required to conduct this research, a test case was developed and learning assessments were conducted to determine the understanding of the students related to steel erection. The project selected for use in this study was a multi-story academic classroom and office building being constructed on the University of Florida campus. Construction on the site of the sample project commenced in the fall of 2013 and image and video data were collected from daily site visits throughout construction. The structural steel assembly system was singled out as the primary focus for this phase of the study and was utilized for the remaining part of the study during the classroom assessments. The scope of the structural steel assembly for the selected sample project included foundation footings, structural columns, structural framing, angle bracing and metal decking.

3.1 Sample Population

The selected population for this study was undergraduate students enrolled in an accredited Construction Management program. For the purpose of this research, the data analyzed is based on a sampling of students enrolled in the Rinker School of Construction Management at the University of Florida (UF). The study was conducted with students in the second semester of their junior year in the program. The Estimating I course, a required introductory estimating course for all construction management students, was selected for the implementation of this study. A total of 55 students, from spring 2015 (29 students) and spring 2016 (26 students) semesters, completed the experimental procedure and provided viable data for use in this study.

4 AR DEVELOPMENT

4.1 Augmentation Procedure

The development of AR-enabled site documentation for the steel structure assembly of the sample project was a crucial step in this research. To achieve the process of augmenting a virtual model onto construction site visualizations, a variety of software packages were used. The research team identified the major elements of the structural steel assembly, as students tend to have difficulty identifying individual steel components. These elements were enhanced and highlighted through the augmentation of BIM components into the real-world visual documentation, both still photography and video based. Portions of the augmentation related to the erection of the structural steel are shown in Figure 1. The virtual model shows the assembly and installation sequence in-situ, to allow for an understanding of the process. This is an example of the augmentations which were superimposed over real-world visuals capturing the entirety of the steel erection process for that portion of the sample building.

Upon 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 steel erection video, with augmentation, was 8 minutes and 37 seconds in length and showed a range of structural erection processes. During the test phases of the study, students were permitted to view the video and progress through it as they saw fit, with no involvement from the proctors. In order to eliminate any excessive influence on the students' individual learning and comprehension experience, text and sound were not incorporated with the visualizations in any way.

Figure 1: Augmentation of steel structure over existing as-built site conditions

5 EXPERIMENTAL PROCEDURE

All participants in the study were initially required to complete a demographic and background questionnaire to determine their contextual experience. The rest of the study was conducted in two phases, with the participants being split into three testing groups, designated as Groups A, B and C. Phase 1 was developed to accurately assess the participants' base knowledge of steel erection processes, after which Phase 2 was implemented to assess the impact the various instructional tools had on the students' knowledge and contextual understanding. The participants in each group were randomly selected and provided with varied combinations of information regarding structural steel assembly based on the group they were assigned to. The information that was made available to each of the three groups is shown in Table 1. In addition to this information, each participant received an identical document set for each of the two phases of the experiment. The Phase 1 documents included the test questions along with an image, derived from the BIM model, of the area and assembly being studied. The Phase 2 documents included a full drawing set, also derived from the BIM model, of the study area including; dimensioned plans, sections, and 3D views.

Table 1: Group designations and associated information streams

Testing Groups	Group A	Group B	Group C
Information Provided	AR Video Only	Lecture Only (Control)	Lecture and AR Video

Phase 1 involved a pre-learning test (pre-test) and was completed at the beginning of the semester, prior to any instruction on the topic. Phase 2, the post-learning test (post-test), was completed during a later class towards the end of the semester when the curriculum reached steel assemblies. Group A completed Phase 2 of the study prior to receiving any formal instruction on the topic from the course instructor. For the integrity of the study, the three groups were separated during Phase 2 and those in groups A and group C were brought to a computer lab where they were provided access to the AR enhanced steel video. The participants in groups A and C had access to the AR video, through a web-based access portal, on individual computer terminals for the duration of the assignment. In addition, the participants were not permitted to discuss their work with one another or ask questions of the proctor.

6 RESULTS

Both the pre-test and post-tests had the same problem-solving skills questions which were designed to accurately assess the participants' knowledge of steel erection. The tests were used to determine whether there was a change in each participant's knowledge or spatio-temporal understanding of the structural steel assembly process, as well as to assess the impact of the various instructional tools used. An analysis of the test questions follows.

6.1 Installation Sequence of Tasks Required to Build the Structural Steel Assembly

The responses to this question provided information on the ability of the participants to identify the necessary tasks required for the structural steel construction process, as well as the sequencing of these tasks. Table 2 shows the suitable installation sequence for the structural steel assembly that was introduced in the estimating class, along with the number of students that listed each item in the answers. The null hypothesis (H_o) postulates that there is no significant difference between the sample proportions, while the alternate hypothesis (H_a) postulates that there is a significant difference between the sample proportions. Equations (1) and (2) show the null and alternate hypotheses used in the 95% confidence level analyses.

$$H_o: \hat{p}_1 - \hat{p}_2 = 0 \quad (1)$$

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

The sample proportions were compared using the MS Excel (2013) statistical analysis add-in. Equations (3) and (4) were used to determine the test statistics of both the pre-test and post-test sample proportions for each element. To test the hypothesis, the p-value, which is then derived from the z-statistics, is used and the null hypothesis is rejected for $p \leq 0.05$.

$$\text{z-statistics} = \frac{\hat{p}_a - \hat{p}_b - (\hat{p}_a - \hat{p}_b)}{\sqrt{[\hat{p}\,(1-\hat{p})(\frac{1}{n_1} + \frac{1}{n_2})]}} \quad (3)$$

$$\text{z-statistics} = \frac{\hat{p}_b - \hat{p}_c - (\hat{p}_b - \hat{p}_c)}{\sqrt{[\hat{p}\,(1-\hat{p})(\frac{1}{n_2} + \frac{1}{n_3})]}} \quad (4)$$

Table 2: Number of observations and sample proportions of installation sequence

Installation Sequence within the construction process.	**GROUP A OBSERVATIONS (VIDEO ONLY)**				**GROUP B OBSERVATIONS (LECTURE ONLY)**				**GROUP C OBSERVATIONS (VIDEO AND LECTURE)**			
	n = 19				**n = 20**				**n = 16**			
Installation Sequence	Pre-Test	p̂	Post-Test	p̂	Pre-Test	p̂	Post-Test	p̂	Pre-Test	p̂	Post-Test	p̂
Fabrication	2	0.11	1	0.05	0	0.00	0	0.00	2	0.13	2	0.13
Excavation	3	0.16	7	0.37	2	0.10	3	0.15	2	0.13	2	0.13
Delivery	1	0.05	2	0.11	2	0.10	3	0.15	3	0.19	0	0.00
Concrete Footings	14	0.74	16	0.84	14	0.70	14	0.70	9	0.56	8	0.50
Columns	10	0.53	14	0.74	13	0.65	14	0.70	9	0.56	8	0.50
Structural Framing	11	0.58	14	0.74	14	0.70	13	0.65	8	0.50	10	0.63
Metal Deck	2	0.11	5	0.26	1	0.05	1	0.05	0	0.00	2	0.13
Welded/ Bolted Connections	12	0.63	13	0.68	9	0.45	14	0.70	6	0.38	8	0.50

The collected data showed with 95% confidence that there were no significant differences (p-value > 0.05) between the control group and the experimental group's answers in regard to fabrication, excavation, delivery, structural framing and metal deck. Table 3 shows the results of the pre-test and post-test null hypothesis testing completed for the data sets of the suitable installation sequence within the structural steel construction process. Significant differences were observed between the control and the experimental groups' answers in regard to concrete footings, structural columns, and connections.

For the "Concrete Footings" item, the post-test sample proportions showed a significant difference between the groups A and B (p-value = 0.011 < 0.05) and groups B and C (p-value = 0.000 < 0.05). Therefore, the null hypothesis for the post-test sample proportions between groups A and B and groups B and C can be rejected, indicating the groups have significantly different proportions after the experiment. Furthermore, for the "Structural Columns" item, the post-test sample proportions showed a significant difference between the groups B and C only (p-value < 0.001) as opposed to the pre-test p-value of 0.074. For the "Connections" item, the post-test sample proportions were found to be significantly different between groups B and C only (p-value < 0.001) as opposed to the pre-test p-value of 0.068.

Table 3: Test results for difference in task sequencing (PS-3)*

Elements	Difference Test	Phase	z-statistic	p-value
Concrete Footings	$\hat{P}_A - \hat{P}_B$	Pre-test	0.610	0.271
	$\hat{P}_A - \hat{P}_B$	Post-test	2.276	0.011*
	$\hat{P}_B - \hat{P}_C$	Pre-test	2.229	0.013
	$\hat{P}_B - \hat{P}_C$	Post-test	3.322	0.000*
Structural Columns	$\hat{P}_A - \hat{P}_B$	Pre-test	2.257	0.012
	$\hat{P}_A - \hat{P}_B$	Post-test	0.610	0.271
	$\hat{P}_B - \hat{P}_C$	Pre-test	1.446	0.074
	$\hat{P}_B - \hat{P}_C$	Post-test	3.322	0.000*
Connections	$\hat{P}_A - \hat{P}_B$	Pre-test	3.452	0.000
	$\hat{P}_A - \hat{P}_B$	Post-test	0.266	0.395
	$\hat{P}_B - \hat{P}_C$	Pre-test	1.494	0.068
	$\hat{P}_B - \hat{P}_C$	Post-test	3.322	0.000*

* $p < 0.05$; H_o is rejected.

7 CONCLUSIONS

The implementation of AR in the construction industry is swiftly progressing and developing in many ways. However, studies have indicated that AR research is not yet widely explored for education in the AECO industry (Rankohi and Waugh 2013). AR has great potential as a possible solution to the comprehension deficiency of construction management students in grasping the complexity of construction processes.

From the analysis of the tasks sequencing question asked during this study, results show that the augmentation video significantly increased the understanding of the students on the identification of concrete footings, structural columns and connections related tasks. This can be attributed to the fact the construction sequence of the structural steel assembly was highlighted and demonstrated in the AR video. The group that had access to the lecture and video had the highest statistical benefits, as they were able to apply the knowledge from the instructor to an accurate visualization of how the structure was erected. It can be inferred from this study that the AR video helped buttress the elements and concepts which were introduced in class and focussed on in the AR content.

The world is undoubtedly changing and moving increasingly towards immersive technology in many industries. As AR tools continue to improve and develop there are increasing opportunities for innovative utilization. This study is a first step in determining the effectiveness of AR for enhancing construction education experiences by introducing the augmentation video as a supplement in the classroom, thus preparing students for successful careers in construction. Further study in this area will aid in the development of effective pedagogical techniques instructors can use to improve the contextual understanding and construction knowledge of their students.

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