Closing the Skills Gap: Construction and Engineering Education Using Mixed Reality – A Case Study

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***Abstract*—This research work-in-progress paper investigated the application of emerging mixed reality (MR) technology in construction and engineering education. The construction industry is facing a severe shortage of skilled workforce. As the baby boomers are retiring, the younger generation, especially college students, are often criticized for their lack of professional experience and career-specific competency. To close the skills gap and accelerate the transition of college students to competent workforce, this paper proposed a new genre of learning and professional training using MR. The main promise of the MR technology resides in its ability to augment virtual contents on top of the physical reality to facilitate tacit knowledge learning, and simulate learning activities that traditionally can only be obtained from actual professional experience. An undergraduate wood framing lab was designed as a case study to explore how students might perform in this new learning and training environment. Specifically, the case study investigated if MR would facilitate student design comprehension and transfer such understanding into the knowledge and skills needed to build the wood structure. A randomly selected student control group was given traditional paper-based construction drawings to perform the same tasks with other student groups with various visualization technology assistance. Project performance and behavior of student groups were compared to determine if there was a significant difference between the control group and the experiment groups. A pair of pre- and post-survey on MR-intervened learning experience was also conducted to explore student perceptions towards this new genre of learning and training. The research design proposed in this work-in-progress study and its preliminary results could be a good reference and foundation to future research in this arena.**

Keywords—mixed reality, construction, workforce, skills, learning

I. Introduction

The construction industry is facing a severe shortage of skilled workforce [1]. Contributing factors are multifaceted and compounded, including the retirement of baby boomers, a rapidly changing technology landscape featured with the wide adoption of advanced 3-Dimensional (3D) modeling and visualization tools, and transformed business practices driven by environmental awareness and smart growth initiatives. The confluence of these issues highlights the need to fundamentally change the way that the built infrastructure is delivered. To remain effective, the building industry must do better with less. This is a major challenge for educators aiming to prepare students who are capable of entering this critical industry with the necessary skills to enable a paradigm shift in how the industry delivers projects. The current state of undergraduate engineering education in the United States effectively import certain types of knowledge (e.g., technical knowledge), but are not as effective at preparing students to integrate knowledge, skills, and affective elements (e.g., identity formation) as they develop into engineering professionals. The consequence of this approach is that engineering graduates entering the workforce struggle to transfer what they learned in school to what is required of them as a professional [2].

Different educators at different institutions have tried various strategies for improving the students' career-specific skill sets. Arguably, one of the most effective modes for preparing students for careers in design and construction fields has been through hands-on, learning-by-doing lab activities, which nourish the development of applied skills in an authentic learning environment. As emerging technologies have become increasingly affordable and robust, there is an opportunity to move beyond traditional classroom to realize a new generation of technology-based learning environments [3]. This research aims to take advantage of this opportunity by leveraging a mobile Mixed Reality (MR) environment, using commercially available tools, to provide an intuitive and immersive learning experience that has not traditionally been possible in classroom settings. This will enable the research team to demonstrate the ability of this cyberlearning technology to enable experiential and situated learning in an effective, yet inexpensive manner. It is anticipated that the research design proposed in this undergoing study and its preliminary results could be a good reference and foundation to future endeavors in this field.

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II. Background

A. Challenges with Traditional Paper-based Communication

Despite recent increases in building information modeling (BIM) use among building industry professionals, which exemplifies the profound transition to the new generation of intelligent 3D design, modeling and construction technology, most formal design communication at the interface between design professionals and constructors is still conveyed via 2-Dimensional (2D) paper documentation. This requires individuals to reinterpret the 2D drawings back into 3D mental models, which hopefully match the design concept defined in the original BIM. In addition to inefficiencies with this drawing interpretation process, it can also be prone to errors, especially for individuals who do not have substantial experience reading plans [4].

B. Current Use of MR in the Industry

MR technologies allow for embodied interaction with science content [5]. By enabling users to experience both the physical and virtual worlds simultaneously, MR environments may uniquely allow students to gain some of the physical exploration benefits that are possible with physical design and construction educational activities, which may enable building design comprehension to support learning. MR is a fairly new concept, but some researchers have begun to explore its feasibility to leverage BIM content and improve project delivery. In the planning stage, MR has been shown to help interacting with prototypes [6] and presenting required data points without interrupting existing workflows [7] to accelerate decision-making processes and provide an interactive view of decisions of real life job sites. During construction phases, MR has been used to visualize planned improvements [8], view hidden objects behind existing structures [9], and monitor construction sites for data collection in documenting construction processes [10]. In these scenarios, MR offers the opportunity of real-time comparison between "as-planned" and "as-built" building elements, which can help to identify defects. MR can also be used for industrial training purposes, namely training operators of heavy construction equipment [11] and teaching students by introducing job-like spatial and time constraints to enhance the understanding of complex situations [12].

C. Learning Theories – Three Apprenticeships & Multimedia Learning

This study relies on the Carnegie Foundation's Three Apprenticeships Model as a lens for guiding the teaching, learning, and assessment components [13]. The Carnegie Foundation for the Advancement of Teaching, an independent policy and research center committed to the improvement of teaching and learning, propose the notion of Three Apprenticeships in response to the need for more integrative learning in professional education. A comparative review of research conducted by the Carnegie Foundation's Preparation for the Professions Program [14] identified the elements of preparation that are necessary for preparing successful professionals in the fields of engineering, nursing, law, medicine, and the clergy. This resulted in three areas that are necessary for development (i.e., apprenticeships to the profession) as people prepare for professional practice. In short, they can be referred to as Apprenticeships of the Head, the Hand, and the Heart. More specifically, these three apprenticeships are:

- Cognitive or intellectual apprenticeship (Head). This apprenticeship includes conceptual or intellectual training to learn the academic knowledge base of engineering and the capacity to think like as engineer. In engineering education, the cognitive or intellectual apprenticeship traditionally is emphasized in the classroom setting.
- Skill-based apprenticeship of practice (Hand). This apprenticeship includes the development of skilled knowhow and professional judgment. In engineering education, the skill-based apprenticeship of practice traditionally is emphasized in the laboratory or workplace settings, with a focus on acquiring competency in skills and tasks.
- Apprenticeship to the ethical standards, comportment or behavior, social roles, and responsibilities of the profession (Heart). This apprenticeship also is referred to as civic professionalism or the responsibility of the profession to the community it serves and traditionally is part of the ethics course content.

This study also leverages the strength of MR as a use case of multimedia learning, which is defined by Mayer [15] as "building mental representations from words and pictures". With the advent of advanced computing technology and visualizations such as Virtual Reality (VR) and MR, educators have the opportunity to supplement verbal instruction with pictorial representations of information. Using multiple forms of media can be useful for promoting meaningful learning for several reasons. Several multimedia studies have shown that learners learn better from situations that engage multiple senses than from instances in which words or pictures alone are used [16, 17]. In the context of this work, simultaneous presentations with multiple senses may be better than one in certain circumstances because the learner has qualitatively different ways of perceiving information.

III. Research Objectives & Methodology

As the initial phase of a federally funded three-year research project, this study aims to conduct a pilot investigation on student learning and skill development in a MR-intervened wood framing lab of a lower-division undergraduate building materials course. The case study is expected to help collect empirical data of student behaviors and learning experiences with MR intervention. Meanwhile, the case study aims to address two research questions (RQs). For RQ1, is there observable performance improvements for students with the affordance of the MR-enabled new genre of learning, in comparison with students using traditional paper-based communication? For RQ2: what could be some of the critical success factors and best practices in research design, data collection and analysis for similar research efforts in the future?

A. Student Demographics & Lab Specifications

The wood framing lab is designed as a group activity in a lower-division building materials course. Students enrolled in this course are typically freshmen and sophomore students majoring in construction management and civil engineering in the College of Engineering. Fresno State is a Hispanic-serving institution. In the College of Engineering, more than 50% of the students are Hispanic and the majority of them are also first-generation college students. In the case study, students were randomly assigned into teams of six and their lab project was to build a wood structure with three wood-stud walls, a floor, a window and a door opening. Teams were supposed to complete the structure using manual labor, small tools and power tools within five three-hour weekly lab sessions. The design of the wood structure is shown in Fig. 1.

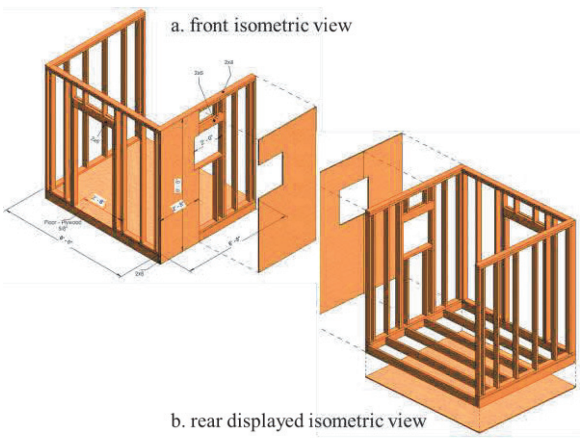

Fig. 1. Wood structure framing and sheathing details.

Major tasks for students in this lab include the handling and processing with building materials such as dimensional lumber and plywood, plan reading, wood structural framing, door opening and window installation. The key challenge to students in this lab is to test if they are able to translate design comprehension and cognitive knowledge of building materials into hands-on skills desired to process and handle materials with appropriate tools, as well as install the required building components following the right means and methods with satisfactory quality and workmanship. In other words, this study focuses on the Apprenticeships of Head and Hand.

The lab will be conducted on an out-door lab site, which includes both a material preparation area and a structure assembly/installation area. Students will be required to comply with appropriate safety guidelines including passing an official safety training program and wearing Personal Protective Equipment (PPE) (e.g. hardhats, visibility vests, working boots, gloves, and protection glasses) during lab sessions.

B. Research Design

This case study uses a comparative approach to test how MR provides students with the extra affordance to enable better apprenticeship learning with focus on the Head and Hand aspects. A total of four students teams are participating in this study, with one control team (*T1*) that uses the traditional 2D drawings as the sole information source. Due to the fact only one MR Head Mounted Device (HMD, i.e. the Microsoft HoloLens) is available when this study is taking place, the rest of the three teams are assigned with different levels of technology intervention:

- one team (*T2*) is assigned with the same 2D drawings with *T1*, plus a Virtual Reality (VR) mobile application and glasses for reviewing VR models via their smartphone;
- one team (*T3*) is assigned with the same 2D drawings with *T1*, plus an Augmented Reality (AR) mobile application for reviewing the design's AR model via their smartphones;
- one team (T4) is assigned with the same 2D drawings with *T1*, plus the Microsoft HoloLens with the design's MR model loaded using a third-party commercial application.

Apparently, there is no real "experimental team" in this sense directly matching the control team (T1). T2 and T3 are configured to provide a supplemental solution to the fact that there are not enough MR HMDs available. T4 is arguably the experimental team except that students in this team are still provided with the same 2D drawings, out of the following considerations: 1) a real experimental team will need Microsoft HoloLens for every student; 2) existing MR applications including the one used in this study is not able to provide key design information, i.e. dimensions of sizes and positions of wood components at the desired precision level; 3) there is an observed learning curve with the use of the Microsoft HoloLens to perform tasks anticipated in this case study, which makes it challenging to train T4 students with desired proficiency with the technology.

Despite the resource and technology constraints discussed above, it is expected the current research design with the four teams setting will still offer insights in addressing the two research questions since the objective is not focusing on whether the MR technology could completely replace 2D paper-based communication, but rather on how its introduction may improve student learning and skill development. This incremental change to existing practices may be more realistic considering the time and efforts will be required to fundamentally transform current practices in the industry. Furthermore, as a pilot study, the use of VR in *T2* and AR in *T3* may provide valuable supplemental information on alternative technology solutions to MR in *T4* in identifying and justifying technology factors and design factors in conducting cyberlearning research in general. The overall research design rationale and team setting is illustrated in Table. 1.

C. Data Collection and Data Analysis Plan

This case study plans to collect qualitative and quantitative data from a range of sources to sufficiently address the two research questions. For RQ 1, in order to evaluate impacts on learning and skills development, direct assessment data of the finished wood structures will be obtained using a grading rubric that encompasses criteria in measure design compliance, material processing, productivity, quality and workmanship. The assessment data will allow a direct comparison of learning outcomes and skill development performance among teams with varied technology intervention. The grade rubrics, together with attendance, are usually used to calculate students' final grades of this lab project.

TABLE I. COMPARATIVE RESEARCH DESIGN AND TEAM SETTING OF THE CASE STUDY

Team		Research Design & Intervention Specifications		
Tag	***Role***	***Paper Drawings***	***Hardware***	***Software***
T1	Control	Yes	None	None
T2	Experiment	Yes	Smartphone, HOMIDO Glasses	Kubity VR
T3		Yes	Smartphone	Kubity AR
T4		Yes	Microsoft HoloLens	HoloLive

For RQ 2, in order to identify critical success factors and observe student behaviors in technology-intervened learning environments, qualitative audio/video data is also collected using a pair of GoPro Hero6 Black cameras. One of cameras is set to record activities at the material handling and processing area and the other records student activities at the installation area (Fig. 2). These audio/video files will be dumped into a secured online data storage provided by Google for Education G Suite. Through these audio/video recordings, it is possible to comprehensively capture the usage of different technology in the given contexts, and to observe possible patterns, human-technology interactions, technology-driven team conversations, and potential issues that may influence both students' behavior and the lab tasks they are charged with. To scientifically analyze and understand the audio/video data, the Behavioral Observation Research Interactive Software (BORIS) is used to for coding and analysis. Behavioral codes are developed to log and compare students' individual and group responses to various visualization technology, and how such technology impact their interaction with physical objects that they're building with. For instance, frequency (counts) and time intervals (duration) between plan reading and actual material handling (e.g. measuring, cutting, placing, installing, etc.) could be used as an indicator of how well/efficient students can extract essential design information with the data format and visualization technology provided.

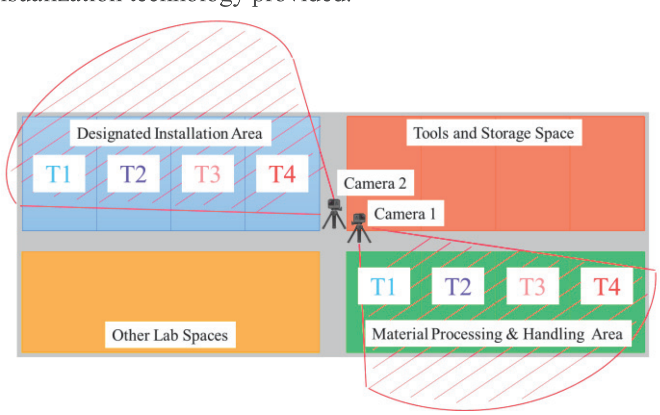

Fig. 2. Outdoor lab layout for audio/vidoe data collection set up.

Last but not least, a pair of pre-/post-test surveys (known more generally as a repeated-measures design) are also used to collect quantitative data [18] for statistical analysis (e.g. paired sample t-test within the teams or one-way ANOVA between teams). A main advantage of using pre- and post-test design is that the associated repeated-measures statistical analyses tend to be more powerful, and thus require considerably smaller sample sizes than other types of analyses [19]. In this case study, the pre- and post-surveys will collect quantitative data that help understand students' perceptions towards various cyberlearning technology and evaluate their impacts on apprenticeship learning and skill development before and after the lab experience. Specifically, the pre-test survey questionnaire collects the demographics information, including students' knowledge preparation in plan reading, building materials, small tools and construction means and methods. It also inquires students' perceptions and expectations towards performing the tasks in the experiment with different visualization technology, measured using 5-point Likert-type scales. The post-test survey questionnaire collects data on students' reflection on experience with the wood framing activities with or without various technology intervention, measured again using 5-point Likert-type scales. The pre-test and post-test questionnaires are linked via the use of identifier questions to allow direct comparison of responses by the same students before and after the lab. The comparison between pre- and post-test surveys aims to determine if there is any significant change in perception and/or knowledge among students due to the introduction of the different technology intervention. Both questionnaires are designed and deployed using the Qualtrics experience management online service, which is made available via the investigators' institution. Both the pre- and post-test survey questionnaires are reviewed and approved by Institutional Review Boards (IRBs) of the two collaborating institutions in this study.

IV. CONCLUDING REMARKS

This work-in-progress paper introduces an undergoing research that aims to close the skills gap in construction industry by introducing innovative cyberlearning technology such as MR into college construction management and engineering curriculum. As an initial phase of a federally funded grand research project, this case study aims to collect preliminary empirical data on student apprenticeship learning and skills development in technology-intervened learning environments. The constraints and limitations of this pilot study will also help identify success factors and observe students' behavioral data for future references. At the time of this paper, the actual case study and data collection process are still ongoing. Nevertheless, this paper offers a comprehensive overview of the motivation, research questions and objectives, research design and methodology, as well as data collection and analysis plan. It is expected that the results and findings from this case study will inform the research design and improvements in the next phase of this project. It can also provide peer scholars with an established method should they plan to conduct similar cyberlearning research in construction, engineering and other STEM programs.

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