Interdisciplinary Collaboration

Design Think Tank | Campus in a Box Student Survey

Overwhelmingly, the architectural and engineering students both viewed interdisciplinary collaboration as highly desirable at the outset of the course. Jeremy Herrin, mechanical engineering student, wrote in his introductory statement “I am interested in pursuing the project because I can apply my skills and learn what it is like to work with engineers in other realms, and architects” (Herrin 2018).

The engineering students reported a level of frustration with the iterative design process employed by the architects. Carter Little, civil engineering student, mentioned in his final report, “The design process moved slowly between ambitious ideas from the architecture portion of the team and recommendations provided by the engineering portion of the team” (Little, 2018).

DOE RTZ Advisor Survey

The advisor survey indicated the DOE competition inspired successful interdisciplinary collaboration. 75% of advisors responded that it was “very much so” a successful model while 25% responded that it was “somewhat” of a successful model. It also revealed that, although over 70% of the respondents indicated their students had different working methods, that the engineering students and the architecture students collaborated quite well together (weighted averages indicate that both disciplines scored approximately a 4 out of 5, with 5 being that they worked “very well together”).

The DOE Race to Zero student design competition as a model for research-based education

DOE RTZ Advisor Survey

The advisor survey also indicated the Race to Zero competition was a highly successful model to exposing students to design research. Over 75% thought it offered a very successful method for exposing students to design research. The other 25% thought it “somewhat” offered a method for design research exposure. Similar to the student survey responses, over 60% of the advisors answered that although the simulation tools were “somewhat” successful in testing options, the competition project timeline did not allow for simulation tools to guide a highly iterative process.”

The DOE Race to Zero student design competition as research tool for the Campus in a Box prototype development.

Design Think Tank | Campus in a Box Student Survey

The student survey indicated that 50% of the architecture students view the RTZ competition as “somewhat” preparing them for the second half of the course – prototype development. The other 50% reported being “minimally” or “not at all” prepared by the competition. And the majority of students indicated that building simulation only contributed “somewhat” or “not at all” to their understanding of shipping container construction. Only 1 student responded that it “significantly” contributed to their understanding of shipping container construction.

CONCLUSIONS

Although it is premature to draw specific conclusions based only on such small sample sizes, the two surveys provide insights into the successes and failures of the class. Comments offered in the engineering student reports offer additional insight. Outcomes indicate that the RTZ competition can be highly successful as a teaching model for interdisciplinary research-based education as indicated by the advisor survey concluding comment: “wonderful engagement…Real-world exposure to life as a collaborator and facilitator. Unique and valuable experience that differs from almost all typical design studios.”

In general terms, the RTZ competition did not offer enough direct translatable research to support the Campus in a Box prototype development, as indicated by the student survey and engineering student comments. Variables that proved to be difficult included time limitations (survey results indicated that a 5 or 6-credit hour studio course was thought to be more appropriate) and the student make-up (5^{th} year Hampton University architecture students are focused primarily on their individual thesis and do not have enough time for the expected level of research). Considering that the students successfully designed a prototype STEM classroom design in the second part of the class, which became compressed into 4 weeks, there may have been more that was translated in terms of collaborative effort and building science understanding that was recognized by the students. One engineering student wrote in his final report that, “The final design considered all the applications and specifications required and was completed quickly. This is due to the large amount of work that was completed prior on the Race to Zero project” (Herrin, 2018). And it may be that over time, the students in the Design Think Tank Class will realize that through the RTZ competition, they learned the basics of a research method that they can apply to future design problems.

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Mixed Reality to Enable Construction Design Comprehension for Digital Natives

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ABSTRACT

The median age of a construction professional has been increasing over the past decade, recently approaching 41 years old. Current reports indicate that more workers are retiring than those entering the industry, leading to an imminent and severe labor shortage. One way of countering the effects of those problems is through attracting younger talent into the industry. One key descriptive of the current young generation is being "digital natives", individuals who have lived their entire life during times of technological advancements. BIM, building information modeling, defined as the development and use of a 3D virtual model containing both physical and functional information, is increasingly adopted for its numerous benefits during design and construction. Researchers have suggested numerous emerging technologies to complement the use of BIM, especially on the construction site. One technology is mixed reality, MR, which enables the viewing of virtual content in the user's field of view. Prior research theorized that viewing designs through MR may enable design communication to trained professionals. This paper explores whether MR can communicate BIM content in a simple enough manner that individuals, without any prior construction experience, could successfully construct the intended building elements. An industry generated BIM is viewed by middle school students through an MR device, and their behavior and design understanding is presented. Specific aspects of design comprehension and participants perceptions are also studied. This paper contributes to the body of knowledge by empirically showing that digital natives can comprehend and build designs using only MR without need for prior training, supplementing the shortage of labor faced in the industry by accelerating their integration into the workforce.

INTRODUCTION

Building Information Modeling (BIM) has expanded in popularity within construction industry over the course of the last decade and is defined as the development and use of a 3-D virtual model containing both physical and functional information that is interoperable (Lee, Sacks, & Eastman, 2006). It serves an integral part in the communication between project team members by providing not only a visual representation of the structure in the context of a 3-D virtual projection, but an interactive digital space in which information can be extracted directly from the model (Gabriel B. Dadi et al. 2014). The advantages of accurately conveying information and supporting preconstruction services have led to the adoption of BIM throughout the construction industry (Wang et al. 2009). Although 3-D BIM is being utilized in the design and review phases of the project, communication during construction is typically done through 2-

D drawings. This requires project team members to view the 2-D documents, interpret them into a mental model of the design concept, and then construct the building element. This process of interpreting 2-D documents into mental models can introduce inefficiencies and opportunities for mistakes due to misinterpretation (Gabriel B. Dadi et al. 2014).

Mixed Reality (MR) has been suggested to be an effective tool in bridging the gap between a completely virtual environment and that of the physical work around the user. MR enables a viewer to visualize BIM content at full-scale in the context of an existing space. This effectively allows for the 3-D model content to be projected into the physical environment of which it is supposed to be constructed. Prior studies have indicated that MR can enhance the ability of constructors to build elements more quickly, indicating cost savings potential in reduction of overall time needed to complete the task (Chalhoub & Ayer, n.d.). In addition, prior research has studied the benefit in using MR as a communicative tool for general visual conceptualization and various use-cases have been studied in relation to field use within construction. However, the ability to leverage MR for technical skill training of new construction professionals within construction has yet to be explored. As the median age of a construction professional approaches the age of forty-one and as number of entering young personnel falls, a labor cliff can be seen to loom in the future of the industry (Bureau of Labor Statistics 2015). A deeper investigation into alternative training processes must be taken into account not only to increase the labor force size, but also to reduce the time required to train that labor force (Albattah et al. 2015). Though previous research has shown promise for MR to be a useful tool for communication, the information collected to this point may not be able to be applied to new young industry professionals. Prior research has primarily focused on older existing members within the industry and this may be the cause of the slow adaptation to newer technologies. Unlike previous generations of workers, new individuals entering into the industry will be some of the first to have a very diverse technological background. This new population of workers have been termed digital natives, individual that have lived their entire lives with technology at their fingertips (Smith, 2002). Presumably, this would bring a comfort level and ability to utilize new technologies not seen in before in prior generations of workers. Therefore this study is aimed at studying the capability of MR as a communication tool to enable non-experienced digital natives, without higher education experience, to effectively construct building elements. This study addresses this by addressing the following research questions: can non-experienced digital natives construct building elements with only the use of MR? And can non-experienced digital natives construct building elements completely and accurate without supplemental technical training?

The contribution of this work is in demonstrating the extent to which MR may be able to enable design comprehension by digital natives without: any prior construction experience; any prior professional experience; or any high school education. This study will aim to provide further insight into the extent to which MR may be able to enable improvements to the training and design comprehension processes required for addressing the labor shortage challenges in the construction industry. While this topic is explored through a middle school context, the findings will provide empirical evidence to justify subsequent studies that strategically target additional use case training applications for digital natives that reflect the new generations of workers entering into the industry.

BACKGROUND

Labor Cliff

Over the last few decades the median age in the construction industry has steadily risen since the recession of 2008 to 42.7 years of age in 2017 with over half of the existing labor force aging between 30 and 45 years of age (Henderson, 2015). With the severe lack of entry into the work force by younger professionals, the industry faces a labor cliff (Sulak Brown, Goodrum, & Taylor, 2015). A labor cliff is defined as a craft labor state in which project performance is significantly affected by one or more workforce issues: labor, quantity or quality (Albattah et al. 2015). The construction industry is faced with the challenge of not only supplying the quantity of labor needed, but also that workers with little to no previous construction experience are trained adequately. The construction industry is expected to see substantial growth in the coming decades, and labor demands are expected to increase to twenty percent for skilled trade positions by the year of 2024 ("Labor force projections to 2024: the labor force is growing, but slowly : Monthly Labor Review: U.S. Bureau of Labor Statistics," n.d.). A robust workforce development effort is needed to supplement and sustain construction labor needs (Albattah et al. 2015). This paper explores the possibility of using emerging mixed reality technology to simplify construction tasks to enable un- or under-trained individuals to successfully construct building elements.

Mixed Reality

Mixed reality (MR) refers to the incorporation of both the tangible elements of the physical environment with that of the modeled virtual environment displayed simultaneously (Milgram and Kashino 1994). This allows users to interact directly with the virtual elements around them while navigating through a space. Within construction, various use-cases have been identified such as site management, inspection processes, on-site construction procedures, and design and constructability review sessions (KIM et al. 2013). In recent years, MR has expanded into educational applications. MR creates an immersive experience for users of which may lend to more effective educational or training programs to be developed (Frank & Kapila, 2017). Within the field of construction, prior work has suggested the potential for MR based applications to enable industry professionals to construct building elements quickly and accurately (Chalhoub & Ayer, n.d.). The success of individuals being able to construct simple building from prior research begs the question of whether or not MR can be leveraged as a training tool for non-experienced individuals to be taught skilled installation processes in a controlled environment.

METHODOLOGY

The purpose of this work is to demonstrate whether MR can serve as a communication tool to enable non-experienced digital natives, without higher education experience, to effectively construct building elements. In order to understand and answer this question the authors worked with a group of middle school students from Phoenix, Arizona. The middle school students had no prior industry experience, nor any vocational training, but did fit the age criteria to be defined as a digital native. Administrative team members of the school lead the selection of the students that would participate in the research activity. This relieved the authors of the responsibility of selecting candidates. Twenty middle school students were selected to participate in the research activity. Participating students' parents signed parental consent forms prior to the experiment.

Students participating in the research activity did not receive credit for this activity and given personal assent forms to participate within the study.

An electrical contracting company supplied two physical electrical conduit assemblies and 3-D models for this research. The models and assemblies provided were comprised of the same prefabricated conduit pieces bent and cut prior to the experiment. The two models differed in orientation and order of placement, but were similar in composition. Each model was prefabricated to resemble industry standard in commercial construction in the context of a simple ground conduit run with an elevated junction box for an outlet. This allowed authors to compare the students' ability to assemble a conduit system similar to one a typical electrical tradesman may find on a construction project.

The MR device that was chosen for this research was the Microsoft HoloLens. This is a spectacle like head mounted display (HMD) in which the operator is presented the MR environment. The device allows for hands-free operation for the user while displaying the 3-D conduit model into the physical world. The models were exported form the native modeling software to the MR device without any alterations. The models were scaled to full size within the MR environment.

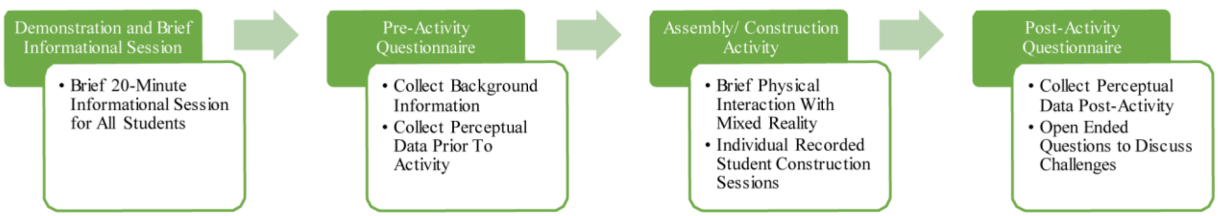

Figure 1: Methodology Sequence

The authors began by leading a brief twenty-minute informational presentation on MR for all twenty students. The students were then given a pre-activity questionnaire to collect pertinent background and perceptual information regarding students' prior experience with construction and MR.

After the presentation, the students were then asked to come back individually to attempt constructing one of the prefabricated conduit assemblies with an allotted time of twenty minutes per student. All construction activities were recorded for future analysis.

During these twenty minute sessions students were first given a more interactive introduction of the MR device. The authors used the preloaded virtual content to display various objects such as an astronaut's helmet and globe of the earth. This allowed students to become comfortable wearing the HMD and interacting with the MR environment. Students were given two minutes for this interaction. The authors then took the MR device momentarily and loaded the electrical conduit models in the specified locations of the classroom. Each physical section of the prefabricated electrical conduit assembly and screwdriver were placed adjacent to the MR projection. The students were then instructed to construct the projected model with the physical pieces to the best of their ability. The authors began to record the time it took to build the conduit system as soon as the student wore the HMD and could view the MR conduit assembly. Time ended upon the students' declaration of completion. The final assembly was then compared to the modeled content by the authors.

The recorded content of these activities were used by the authors for detailed analysis of the building process of each student. Figure 2 describes the criteria of which the authors used to examine each student. The video content was gathered through the use of fixed cameras placed in the room of the activity and were then reviewed using time stamp behavioral coding software. This allowed the authors to assign time values to each assembly task and define user behavior throughout the activity.

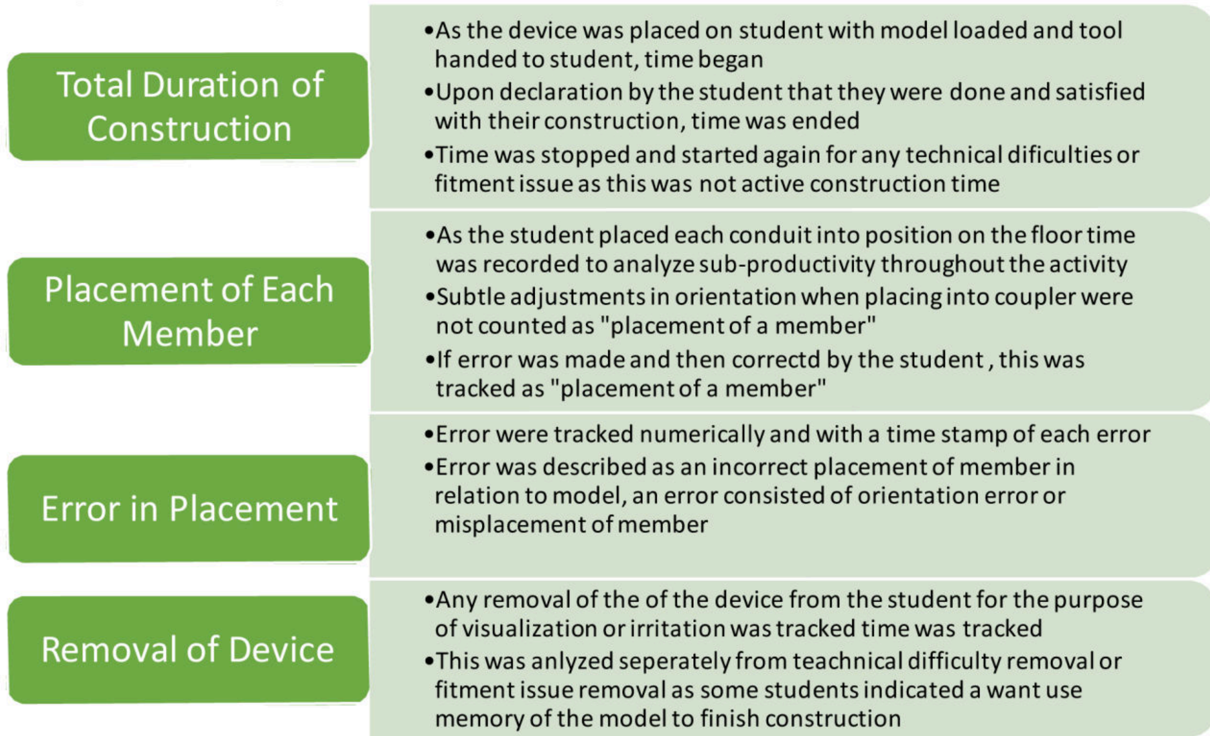

Figure 2: Criteria for Analysis

After completing the assembly, the students were given a post-activity questionnaire regarding their experience with the device. The focus of the questionnaire was the overall experience of the students using the MR environment for construction of an electrical conduit assembly and an updated perception on their ability to construct the conduit assembly. Figure 1: Methodological Sequence provides an overview of the methodology used to conduct this research.

RESULTS AND DISCUSSION

Twenty middle school students, ranging in grade levels from sixth to eighth grade, participated in this research. All twenty students examined were able to handle the device, maneuver, and guide themselves through the space without prior training with any MR device. None of the students had any prior experience with assembling conduit systems or were given paper documents to follow. All twenty of the middle school students were able to complete the task of assembling the conduit system using the MR headset in the allotted build time of twenty minutes. All twenty of the students had prior experience with virtual environments, most commonly in a video game setting. Only one of the twenty students had any prior experience with a MR device.

The average duration of assembly of the conduit systems was 509 seconds. The maximum time recorded was 834 seconds and the minimum time was 199 seconds. All times recorded of the twenty students lie within two standard deviations, indicating a normal distribution of the data. The standard deviation between the students recorded times was 192 seconds.

Table 1: Middle School Data

Average Duration	Minimum Duration	Maximum Duration	Standard Deviation
509 seconds	834 seconds	199 seconds	192 seconds

In a previous research effort, current industry professionals were examined in a similar fashion. Industry professionals were tasked with assembling the identical set of conduits systems used in this research activity, using both traditional paper document plans for assembly and a MR device for assembly. The total duration of assembly was recorded for each participant. The study found that with the use of the MR device in comparison to use of traditional paper plans for construction yielded quicker and moderately more accurate assembly (Chalhoub & Ayer, n.d.). The authors used the data from the industry professionals using the traditional paper plans for construction to run a similar comparison and identify whether non-industry professionals could produce the similar results. Using an independent two samples t-test, the time of the middle school students to that of industry professionals were compared.

Table 2 Statistical Comparison to Industry Professionals with Paper Drawings

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
MRTime	.094	36	.926	5.82028	61.98812

The t-test shows that there is no significant evidence to indicate that the two performances are different.

Amongst the twenty students examined, there was an average error rate of 1.45 mistakes per student during the assembly of the conduit system. Eighteen students (90%) made a mistake or error during construction. Figure 2 indicates the criteria of which constituted in an error. Conduit assemblies generated by the students were considered complete upon declaration of completion from the student. Each assembly was then compared against that of the content presented to the students through the MR device. If the conduit assembly matched in form to the model content presented, the student was recorded as completing the assembly of the model.

The mistakes made by students came in two primary forms, orienting a conduit member incorrectly during or after assembly or orienting junction boxes in the wrong direction. The students were assumed to have the capacity to construct the conduit assembly even with the presence of a mistake through construction as each mistake came in the form of orientation error was considered due to lack of industry knowledge that would need further explanation or lack of granularity demonstration through the model. This was concluded due to the frequency of t he identical error amongst the students and locations at the junction boxes in the model.

CONCLUSION

Throughout the course of the research, the ability of MR to effectively enable non-experienced digital natives to accurately construct building elements was examined. MR proved it could plausibly be used as a communicative tool to convey building information, in adequate detail that digital natives can effectively follow and emulate. As proof of concept, Middle school students were chosen as the baseline sample to reflect digital native and to determine if these participants, with little to no prior industry experience, could still successfully construct building elements. This group of participants does not serve as a direct comparison of individuals already active in the construction industry, but it provides initial data to illustrate the extent to which newly entering digital natives without any industry background, construction expertise, or higher education may be able to use MR for prefabrication.

The outcome of this research suggests the potential validity in implementing MR to perform simple construction tasks. This may allow for the development off-site comprehensive skills training for new workers entering into the construction industry and reduce the time necessary to train said workers. Future work will serve to examine the complexity of information of which can be accurately displayed through MR to hone more developed skills of which can be transferred to the jobsite. Additionally, it will aim to further understand how to more effectively convey information to users via MR and what may benefit the experience to develop a framework of which to generate various applications for different construction training use-cases. This may enable a safer method of training non-experienced digital natives in a controlled environment away from safety concerns on the jobsite. Additionally, it may enable the development of more intuitive educational experiences for students who may not be able to be physically present for construction.

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