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PERCEPTION OF INDUSTRY PROFESSIONALS ABOUT MIXED REALITY FOR ELECTRICAL PREFABRICATION

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Abstract: The use of Building Information Modeling (BIM) has been steadily increasing in the building industry. This increase has led many project teams to assess design and constructability for projects in a 3D, BIM-based, environment. Despite this increased use, many projects still use traditional 2D documentation to communicate design concepts to various project participants. Mixed Reality (MR) can technically be used to visualize 3D design content without the need for 2D paper communication, but in practice it is not clear how users would feel about replacing traditional 2D drawings with 3D MR models. This research investigates the perceptions of industry professionals about replacing paper construction documents with a 3D MR based model. To evaluate behavioral and ideological patterns and changes, 18 electrical construction industry practitioners built two different conduit models using the same prefabricated pieces. In one iteration, they were provided with design communication through a MR visualization interface. In the other iteration, they used traditional paper plans. A pre-activity questionnaire was given to capture their ideas about a new technology being introduced and a post-activity questionnaire helped to evaluate their thoughts after using MR to build the conduit. During the conduit assembly activity, participants were video and audio recorded to capture any verbal comments related to their perception of the activity. Participants showed a wide array of reactions to the technology. Although participants unanimously reported that MR was easier to use than paper plans, some voiced other concerns. For example, some participants considered to only be effective as an educational tool. Some participants suggested it could supplement, but not replace, existing paper plans, while others thought it could indeed be used as the primary design communication method. Future research will study the relationship between perception and performance of the participants in this session.

1. INTRODUCTION

In the past few decades, the construction industry has been criticized as inefficient and lagging in modernization (Teicholz, Goodrum, and Haas 2001). Furthermore, it has been suggested to be dependent on an aging workforce, which is not predicted to be effectively replaced by an equal incoming workforce of young professionals, which has led to an impending “labor cliff” (Albattah et al. 2015).

In more recent years, the industry has made various attempts to modernize. One prime example of this is Building Information Modeling (BIM). BIM is becoming more widely used in the AEC industry, especially among contractors. This may be due to the observation that contractors have overtaken designers as the primary users of the technology for the first time in 2012 (McGraw-Hill Construction 2014). Contractors and subcontractors have also turned to prefabrication, which has been proven to increase productivity, allow for better quality control (Arditi and Mochtar 2000) and reduce construction related waste (Tam et al. 2007).

Despite the potential offered by BIM to communicate design information in a 3D environment, the main medium for design communication between design offices and site workers continues to be 2D documentation. Designers often create BIM content in 3D, but then reduce that content to 2D documentation to illustrate the desired finished product. This 2D documentation then must be reinterpreted into 3D mental models before being built by constructors on site. This process can potentially lead to misinterpretation of the design, which could lead to an undesired finished product. This has the potential for ramifications related to increased: rework, cost, waste, and schedule for the project.

Mixed Reality (MR) has the potential to remove the need for this type of 3D (BIM) to 2D (paper) to 3D (mental model) reinterpretation process. Instead, MR would allow for 3D content to be represented in the corresponding, physical, space at full scale. This would mean that construction personnel could theoretically view BIM content exactly as intended without having to reinterpret any of the 2D design documentation. While this process is technically possible from a computing standpoint, truly moving to a MR-based design communication that would in effect, eliminate the need for traditional plans would constitute a major paradigm shift for design communication. It is not clear how a shift like this would be perceived by current industry professionals.

This paper investigates the potential usage of MR as an onsite design communication tool. Specifically, it addresses the following research questions: how do industry practitioners perceive MR as a design communication tool? And what is the effect of an individual's background on their perception towards the reception of MR in the workspace? The findings of this work may help to shape the development of future MR applications that will provide the technological value offered by the visualization strategy without alienating potential users with undesirable user interface restrictions.

2. BACKGROUND

2.1 Information Delivery

In the construction industry, six Key Performance Indicators (KPI's) have been identified to evaluate construction projects, including productivity (Cox et al. 2003). Productivity is highly affected by information delivery and communication (Dai, Goodrum, and Maloney 2009). Specifically, better productivity has been associated with information delivery methods requiring less mental loads (Dadi et al. 2014). For example, a physical mockup used as a design communication tool required a smaller cognitive workload compared to 3D CAD models displayed on 2D screens or traditional 2D drawings (Dadi et al. 2014). While these findings are largely intuitive, the prior studies help to empirically validate these assumptions and demonstrate the importance of effective design communication.

2.2 Prefabrication

Prefabrication has also been shown to increase the productivity and finished product quality for certain tasks (Arditi and Mochtar 2000). Many electrical subcontractors in the Southwest region of the United States have adopted this construction strategy. Prefabrication takes place in the shop, where conduit pieces are cut and bent. The prefabricated pieces are then transported to the site where they are assembled in place by connecting the different pieces in a given order.

With recent advances in BIM, it is becoming even more effective and desirable to use prefabrication in a project, since all information required for the success of implementing prefabrication can be streamlined and included in one model (Lu and Korman 2010).

2.3 Mixed Reality

Mixed Reality (MR) is a visualization method that combines virtual and real objects (Milgram and Kishino 1994). If the scene being visualized is mostly comprised of virtual elements, MR is referred to as Augmented Virtuality (AV). Conversely, in a scene mainly comprised of real elements, MR is referred to as Augmented Reality (AR). In this research, the authors focus on the AR aspects of MR applications.

In construction, MR has been used on the job site to visualize planned improvements (B. Thomas et al. 2000) and hidden objects behind existing structures (B. H. Thomas and Sandor 2009). MR has also been used for site monitoring and data collection (Zollmann et al. 2014). Recently MR has been used to leverage BIM usage and visualization on site through the projection of the BIM on real site using mobile camera view (Kopsida and Brilakis 2016).

In recent years, MR technology has been combined with new Head Mounted Displays (HMD), projecting 3D objects directly onto the user's field of view. This allows an untethered 3D MR experience, where the user can interact and observe 3D models without being wired to a computer. MR may be able to replace paper plans as the main design communication tool by showing the full 3D model instead of 2D views of a given design. This could potentially offer some of the intuitive design comprehension benefits seen with traditional physical mockups, while also providing some of the highly modifiable attributes of purely virtual models. However, it is important to understand the perception of industry professionals towards the technology before wide implementation, as labor cooperation (Dozzi and AbouRizk 1993) and learning curves (Dozzi and AbouRizk 1993; Adrian 1995; Kazaz, Manisali, and Ulubeyli 2008) are important factors affecting productivity. This paper explores the critical aspect of industry practitioner's perceptions of a new technology used for information communication and delivery. The MR technology studied is developed and implemented with the aim of improving the productivity of on-site assembly of prefabricated electrical conduit.

3. METHODOLOGY

This research examines the perception of construction professionals towards the use of MR as a design communication tool. The authors have collaborated with an electrical construction company located in the Southwest United States for the purposes of this research. The subcontractor's typical workflow includes: designing all of their conduit sets using a BIM software; generating plan, isometric, and detail views; printing them on paper; and using those sheets for shop prefabrication and site assembly. In effect, this enables site personnel to receive a pre-made kit of parts that should fit exactly into the framed construction space. To support this task, each set of conduit typically has a set of paper plans showing an isometric representation of the conduit, a plan view sheet, and as many detail sheets as necessary. This requires the construction personnel to interpret the printed plans in order to assemble the pre-cut and pre-bent conduit components.

Figure 1: The two conduit assemblies used

For the purposes of this research, the subcontractor designed two conduit assemblies that use the same set of prefabricated pieces in different orientations (Figure 1). The design, prefabrication and design documentation procedures followed the firm's established workflow. Two sets of plans, one from each assembly were also provided by the firm (Figure 2). Since both assemblies use the same pieces, it is assumed that they are comparatively hard to assemble, and the difficulty would not affect the user's perception of the design communication technology used.

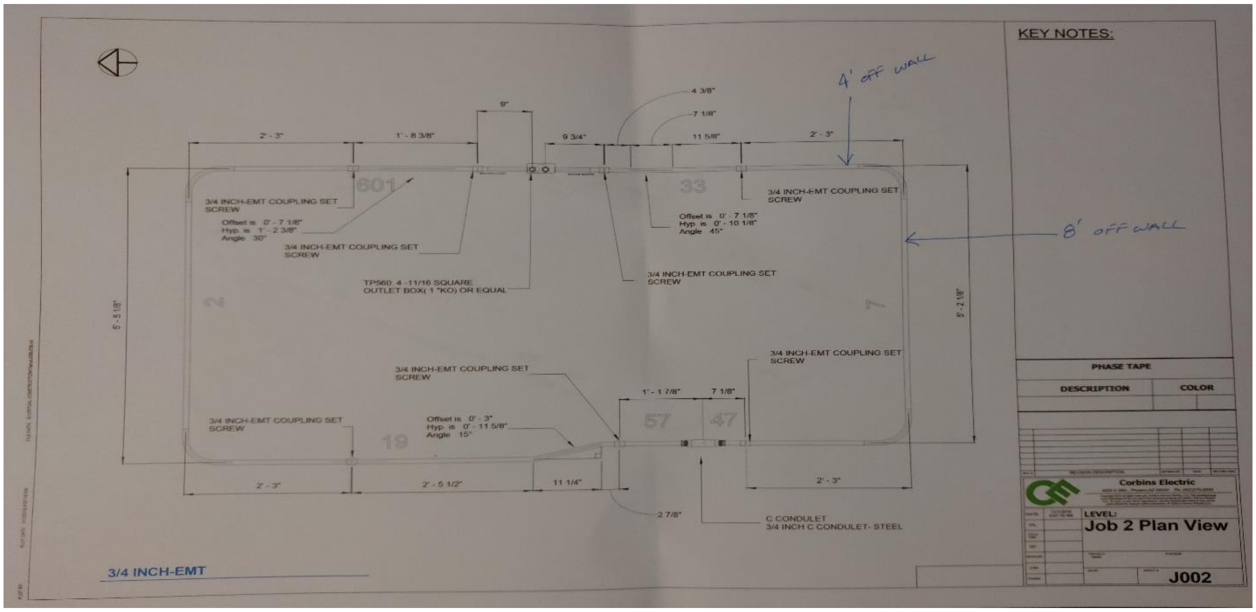

Figure 2: Typical Paper plan used for electrical conduit assembly

For the MR visualization method, the authors used a Microsoft HoloLens. The device has a see-through visor that allows the projection of 3D holograms in the user's view. The user can then walk around the Holograms and interact with them like real life objects, but also capable of hands-free viewing. For each conduit assembly, the authors used a copy of the 3D model, exported it to a MR compatible software, and loaded that model onto the HoloLens. The models were displayed at full scale with opaque transparency, as shown in Figure 3.

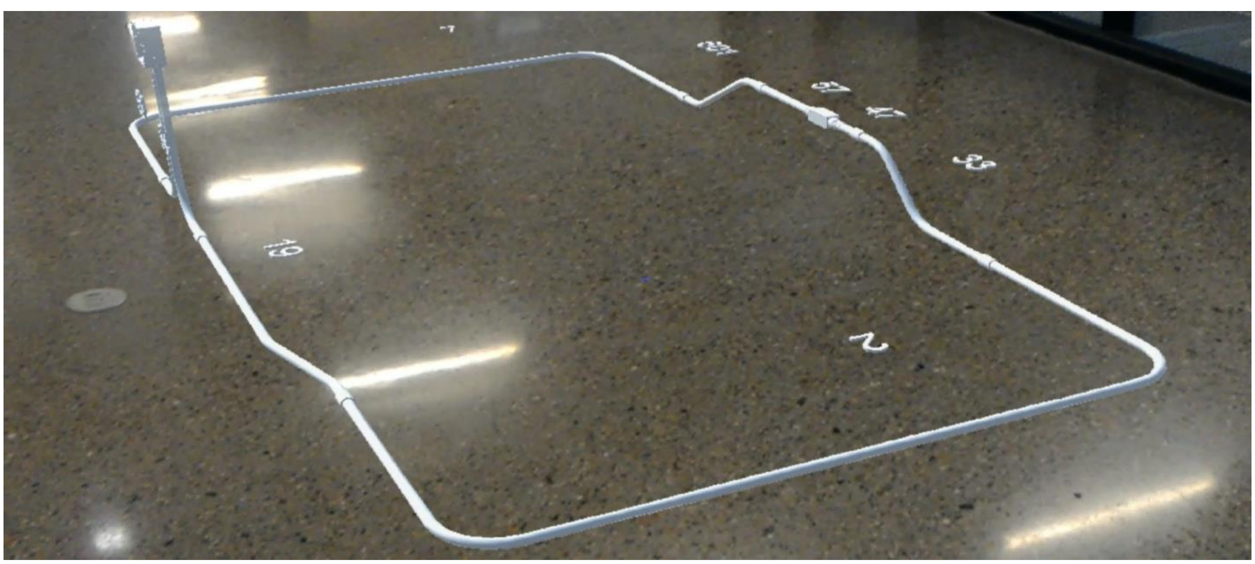

Figure 3: Electrical conduit as viewed from the HoloLens, placed on the ground

All participants were industry practitioners, with varying positions, roles, and years of experience. Prior to the start of the session, all participants signed and kept a copy of an informed consent form, in accordance with the study's Institutional Review Board certification. A pre-session questionnaire was also filled by all participants. The questionnaire included questions to elicit general information from the participants, including years of experience, position within the firm and percentage of time spent assembling electrical conduit in the past year. Additionally, the questionnaire included questions about the experience of the participants with using MR in construction. Finally, participants were asked about their perceptions of MR prior to using the application. A sample of the questions are represented in Table 1.

In general, most participants had little experience with MR and the HoloLens device. Therefore, prior to beginning the conduit construction activity, participants were assisted with wearing and adjusting the HMD for comfort. Then each participant was given a five-minute introduction to the device. This introduction involved loading holograms that were unrelated to construction to give each participant a chance to walk around the virtual objects and familiarize themselves with the process of interacting with virtual objects while wearing the device. This enabled each participant to have some familiarity with a MR environment prior to the timed construction activity.

After participants were provided with a MR introduction, they were asked to build each conduit assembly once. One of the two models would be built using paper plans as the only design communication tool, and the other with MR as the only design communication tool. The participants were divided into four groups: participants from groups 1 and 2 started with the model 1, and participants from groups 3 and 4 started with model 2. However, participants from groups 1 and 3 used MR first then paper plans, and participants from group 2 and 4 started with paper plans and then MR. This meant that all combinations of precedence were exhausted, mitigating any potential bias in the results. It should be noted that the participants saw the designs of each conduit model for the first time through the chosen communication method, and had no previous knowledge of the chronology of events of the session.

The participants were audio and video recorded for timing and analysis purposes while assembling the conduit models. After each participant was done with both models, they were given a post-session questionnaire with questions focusing on their experience and thoughts regarding MR for design communication, along with other relevant multiple choice questions and several open-ended questions to capture any thoughts they might have. A sample of the questions are represented in Tables 2 and 3.

All data collected was entered into a statistical software, and number coded for ease of analysis. A frequency analysis was done on all data. A pre-and post-session analysis was done to reflect the change of perception before and after the completion of the experiment. In the open-ended questions, patterns emerged concerning limitations and opportunities using the technology. Several other open-ended questions were used to guide and inform future research.

4. RESULTS AND DISCUSSION

4.1 Pre-Questionnaire

Eighteen construction practitioners participated in the session. Nine of the participants had less than one year of experience and five had more than ten years of experience. 45% of the participants reported not spending any time assembling electrical conduit as part of their job in the previous year, those had roles in as shop workers or having management positions within the firm. Most of the participants had not used MR as part of their jobs before (78%). The remaining few had used models shown through phones, tablets and data vaults, which are loosely connected to MR through HMDs like the one tested in this session.

Table 1 showing sample pre-questionnaire questions and multiple choice answers

Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Mixed Reality can completely replace paper plans for communicating electrical conduit designs for construction in the field	0	4	8	4	2
I am looking forward to eliminating the use of paper plans and relying only on digital means of design communication	0	2	7	7	1
Mixed Reality will be easier to use than paper for the purposes of electrical conduit construction	0	2	6	8	1

*Some participants did not choose any answer for some questions

The questions in the pre-questionnaire focused on the status of using MR for electrical construction purposes and the participant's mindset towards relying on digital means for design comprehension (Table 1). Only 11% of participants thought that using MR as a design communication tool would be harder than using paper plans. Even before being exposed to the technology, the participants largely expected it to be superior to traditional paper plans in terms of usability. This could mean that construction practitioners know and accept that paper plans can be challenging to comprehend and use.

When asked if they are looking forward to eliminating the use of paper plans and relying on digital means for design communication, be it Mixed or Virtual Reality, it was encouraging to see 45% of the participants agreeing to the statement and 39% being neutral to it. Only a small minority of participants considered the paper plans irreplaceable under any circumstances, while the remaining where at least open to the idea of replacing paper plans.

However, when asked to choose their preferred means of communication on site, only 33% of participants believed MR could completely replace the use of paper plans on the field. When given the chance to "choose a preferred technology to assemble conduit", 67% of participants preferred to at least keep paper plans as part of their design communication suite required to assemble electrical conduit on site, and only 22% preferred to rely on digital means. Although MR is viewed as easier to use and many participants eager to replace paper plans, many chose to keep paper plans as part of the information communication suite to be used on site. Technologies not relying on paper plans seem to be viewed as less reliable, and more prone to technical problems, while paper plans are universally viewed as reliable and resilient, being used for the past century as main information communication channel. Another explanation could be that MR is viewed as a less mature form of communication, perhaps seen as less robust and encompassing compared to paper plans, or simply because the participants are simply accustomed to using paper plans.

4.2 Post-Questionnaire

After going through the session and building both conduit models, the participants answered the questions in the post-questionnaire. The questions in the post-questionnaire focused on the actual experience of using MR as the main design communication tool compared to paper plans.

All participants believed it was easy to use MR as the main design communication tool to assemble pre-fabricated conduit compared to paper plans. 67% of participants believed they could "effectively build electrical conduit using MR without needing traditional paper plans". 67% also stated that it was "easier to assemble electrical conduit using MR compared to using paper plans". This indicated a 25% increase in responses indicating ease of using MR over paper as compared the pre-activity responses. While there were 33% of individuals who were neutral about the statements, not a single participant stated that they actively disagreed with either statement.

Table 2 showing sample post-questionnaire questions and multiple choice answers

Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
With Mixed Reality, I can effectively build electrical conduit without the need for traditional paper documentation	0	0	6	5	7
It is easier to build conduit using Mixed Reality than Paper Plans	0	0	6	5	7
It would be easier for inexperienced individuals to build electrical conduit with mixed reality than with paper plans	0	0	2	7	9
I would rather use Mixed Reality than use Paper plans for assembling pre-fabricated electrical conduit	0	1	6	7	4

From a usability standpoint, MR is not only perceived as an effective design communication tool, but a superior one compared to traditional paper plans. Moreover, participants had little training only at using the device and not assembling conduit using it, but could complete the task with relative ease. Generally, it is much harder to assemble conduit using paper plans without proper training. when asked Only one of the eighteen participants said that they would still rather use paper plans than use MR to assemble electrical conduit, while eleven said they would prefer MR over paper plans.

Table 3 showing sample post-questionnaire questions and multiple choice answers

Questions	Mixed Reality	Paper Plans	MR and Paper Plans
For training new individuals to build electrical conduit, it would be best to use	1	1	16
For the newly trained individual, on real life site, it would be best to use	4	2	12

The participants were asked about using the technology with new, inexperienced labor: in general, 89% believed it would be easier for them to use MR to assemble prefabricated electrical conduit rather than using paper plans, but believed they should be trained using both visualization interfaces. The participants were then asked what tools they would use to train new individuals coming in the industry, and what those newly trained individuals should be using on site. 89% of respondents believed that trainees should be trained using both technologies, with one respondent considering MR alone enough, and another considering paper plans enough. Interestingly. The answers were more diverse on the second question: 22% of responders think Mixed Reality will be enough for new individuals on site, 11% think paper plans are enough, and the remaining 67% consider both needed.

Examining the results more closely, the participant who chose to train new individuals using paper plans also believed that they should rely solely on MR on site. The two participants who chose to use paper plans on site chose to train individuals using both paper plans and MR. This means that MR is viewed as good training tool by some as preparation to use paper plans on site, while others view it as usable on site without even the need to be trained on using it. However, most participants believed that both communication technologies are important to be trained on and used on site.

To further explore trends in the responses, the participants' experience was also documented and correlated with their Likert-scale responses to these perception-based questions. It was interesting to note that in all cases, there was no observable correlation. It is possible that this means that older and younger personnel both see MR similarly, but it is also possible that the relatively small sample size of individuals from the particular company chosen simply did not illustrate a direct difference in perception based on experience.

In responding to the question “what did you like best about the experience?”, the participants repeated two main ideas: (1) the clarity and placement of the model, and (2) how they didn’t have to keep going back to look at the paper plans: by having the life-size design in front of their eyes at all times, the participants were able to build the conduit more easily and effectively with constant validation, in their opinion.

The participants also reported a number of technical and model limitations of the MR approach. First, the participants repeatedly complained about the brightness of the model as visualized: some considered it too bright, and other considered it not bright enough. This can be easily adjusted to the user’s preference, but the users did not know how to use the HoloLens because of the very short training the received. Other users asked for different color options for the model as viewed. Weight and fit are other aspects of the device that the users had difficulty with, some considering it awkward to wear and front heavy, putting pressure on the head of the user.

Finally, the field of view of the device was a common issue cited by the users: although the device is completely see-through, only a relatively small area of the visor can project holograms, creating a “box effect”. Users complained that the field of view is too narrow, and making it bigger would give a better view of the model, especially for larger implementations.

5. CONCLUSION

This work examined the perception of industry professionals towards the use of MR as a design communication method. MR may be able to replace paper plans as the main design communication method, with potential benefits on productivity and better design communication leading to less rework on site. However, this type of technological change could potentially be considered drastic by users. Therefore, understanding the potential response of industry practitioners proves valuable to researchers and industry members considering adopting this approach to design communication. While there was some reluctance observed in this toward MR before trying it, after using it to assemble an electrical conduit models, practitioners found it unanimously easier to use than paper plans. However, the participants believed that new employees should be trained using both paper plans and MR, both in the office and on site. Although MR seems to be perceived as easier to use, participants seem to be reluctant to fully rely on it as the only technology on site. The openness to the use of MR among many of the industry practitioners may indicate that this mode of communication could be positively received by additional practitioners if the technology is reliable. Future research that explores a larger pool of participants in different use-cases may help to further indicate how the technology would be received at a larger scale.

Future work will focus on analyzing the relationship between: a participants’ background and perception; and their performance using either form of design communication. This will allow researchers to assess the effects of implementing this technology on the productivity of workers with different skillsets and experience levels. This may reveal where the implementation of MR might be the most valuable for productivity of the construction process and where it might be most positively received by the human users.

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