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EXPLORING THE USE OF MARKER-BASED AUGMENTED REALITY FOR DESIGN COMMUNICATION IN ELECTRICAL INSTALLATIONS

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ABSTRACT: Integrating augmented reality (AR) technology across various industries has demonstrated significant utility, particularly in the retail and marketing domains. While the adoption of innovative technologies such as AR and building information modeling (BIM) is growing in the construction sector, especially among larger contractors, small contractors with fewer than ten employees continue to face significant challenges in implementing these solutions, primarily due to cost barriers. This research investigates the effectiveness of low-cost AR technology solutions to enhance design communication during electrical installations. The study proposes a marker-based AR approach utilizing handheld mobile devices such as smartphones and tablets instead of expensive head-mounted devices (HMDs) such as the Microsoft HoloLens. By scanning quick response (QR) codes as markers, users can access corresponding BIM models and pertinent information necessary for executing construction tasks. The key contributions of this study include (1) developing an implementation workflow for marker-based AR in electrical installations, (2) identifying user experience factors that impact adoption among small contractors, and (3) providing evidence that marker-based AR represents a practical, intuitive, and cost-effective alternative for onsite applications in electrical installations. Findings suggest potential for broader adoption of this approach among smaller contractors in the construction industry.

1. INTRODUCTION

Over the years, construction industry researchers have explored various technologies to enhance design communication for project execution(Webster et al. 1996). Professionals within the industry anticipate that innovations such as virtual reality (VR), augmented reality (AR), and other three-dimensional visualization tools will lead to significant performance improvements (Monla et al. 2023). One influential concept in this realm is mixed reality (MR), which Paul Milgram defined as blending real and virtual worlds along the reality-virtuality continuum (Milgram et al. 1995). This continuum ranges from completely real environments to entirely virtual ones. Technologies closer to the virtual end are known as augmented virtuality, whereas those near the real end are classified as augmented reality. Thus, AR is characterized by its tendency toward enhancing the real world instead of creating an entirely virtual environment (DaValle and Azhar 2020; Milgram et al. 1995). AR involves enriching the physical environment with computer-generated information, often in the form of graphical overlays, to improve user interaction with the real world (Kalawsky et al. 2000). Despite the potential benefits of AR technology, its adoption among small construction contractors remains limited (Davila et al. 2020). The high cost of AR implementation and the complexity of integrating it into existing workflows pose significant barriers. Additionally, HMDs usability has been challenging, as these devices can be cumbersome and economically unfeasible for smaller firms (Billinghurst 2021; Oke and Arowoiya 2021). There is a pressing need for more accessible and cost-effective AR solutions that small contractors can seamlessly adopt to enhance design communication and onsite safety.

This research examines how AR enhances design information communication for electrical installations. The objectives of this research are threefold: First, to investigate the adoption of AR by small construction firms for design and construction projects in the Houston area. Second, to develop a workflow for the integration of marker-based AR in electrical construction processes. Third, to evaluate the effectiveness of marker-based AR as a communication strategy for design in electrical installations.

The subsequent sections examine the application of AR technologies within the construction industry, focusing on small contractors. The literature review analyzes research on marker-based AR technologies, emphasizing their implementation in construction and effectiveness in enhancing design communication and safety. The methodology section outlines a two-part approach: (1) a survey of construction professionals in Houston to determine the current state of AR adoption and barriers, and (2) an onsite demonstration of AR-based visualization for electrical installations. Data from the survey and demonstrations measure the effectiveness of AR technologies in improving design communication and safety. The paper concludes by discussing the potential benefits and challenges of adopting low-cost AR solutions for small contractors.

2. LITERATURE REVIEW

AR visualization technologies are categorized into markerless AR and marker-based AR technologies. A marker is a two-dimensional computer-recognizable graphical pattern or symbol printed on a sheet of paper to which a piece of information (e.g., video, audio, text, diagram, or graphics) is assigned (Behzadan and Kamat 2013). Marker-based AR executes AR by using a marker. Markers in AR serve as reference points that trigger digital content when recognized by an AR system. Markerless AR seamlessly overlays digital content onto real world scenes without the need for specific markers (Mubarak et al. 2020). In marker-based AR, a virtual object is displayed only if its corresponding marker pattern is visible. An example of this is the Lego Digital Box technology at Disney World (Behzadan and Kamat 2013).

Various studies have shown the effectiveness of MR/AR in designing communication compared to traditional methods (Rankohi and Waugh 2013). Chalhoub and Ayer (2018) conducted a quasi-experiment comparing the performance of electrical construction personnel assembling conduits using traditional paper drawings versus using MR through a HMD. The results indicated that MR significantly improved productivity rates, design comprehension, and interpretation speed. While such applications demonstrate the potential of AR technology, they often require substantial financial investment and technical expertise that small contractors lack. Davila Delgado et al. (2020) specifically identified cost and technical complexity as primary barriers to AR adoption among small construction firms.

Recent developments in marker-based AR represent a promising alternative for small contractors. QR codes and other marker-based systems offer a more accessible and cost-effective approach to AR implementation. Oke and Arowoiya (2021) identified that marker-based systems using mobile devices significantly reduce the technological and financial barriers to entry compared to markerless systems requiring specialized equipment. Mobile-based marker systems leverage devices that most contractors already possess, eliminating the need for additional hardware investment.

For electrical installations specifically, marker-based AR can provide significant advantages in design communication and error reduction. Improved design intent interpretation facilitates better construction, reducing the need for change orders, reworks, and waste. Billinghurst (2021) notes that marker-based AR systems are particularly well-suited for task-specific applications like electrical installations, where precise placement and component identification are critical.

Furthermore, Oke and Arowoiya (2021) noted that small contractors have distinct requirements for AR solutions that differ from those of larger firms. Their research indicated that small contractors prioritize: (1) solutions that work with existing hardware like smartphones and tablets, (2) minimal training requirements, (3) immediate practical application, and (4) clear demonstration of time and cost savings. Traditional AR research has primarily focused on capabilities and technological advancements rather than addressing these specific needs of small contractors.

This research builds upon these findings by developing and testing a marker-based AR workflow specifically tailored to the needs and constraints of small contractors performing electrical installations. By focusing on affordable, accessible technology solutions, this study addresses a critical gap in the literature regarding AR implementation for smaller construction firms.

3. METHODOLOGY

The authors surveyed the construction industry to understand AR usage and tested workflows for implementing AR. The construction industry survey was distributed online to construction professionals in Houston, Texas. A 3D model presentable in AR application was developed to use for testing AR effectiveness for design communication.

3.1 Industry Survey Design and Implementation

The industry survey consisted of fifteen questions divided into three sections: demographic information about the respondent and their organization, current technology adoption practices, and specific questions about AR awareness and implementation. Key questions included the size of the organization based on the number of employees, the respondent's current role within the organization, whether the organization had utilized visualization technologies such as VR, AR, MR, or others, the purposes for which these technologies were used, the main reasons for not adopting AR/MR technologies, and the organization’s interest in implementing AR/MR technologies if they were more accessible. The survey was distributed via email to construction professionals in the Houston area using contact information obtained from local construction associations. Participants were given two weeks to complete the survey, with a reminder sent after one week.

3.2 AR Model Preparation

A 3D drywall model compatible with the AR platform was created using Trimble SketchUp Pro. The task involves installing a power outlet. An augmented reality application, REXView, was utilized for visualization, with its plug-in integrated into SketchUp Pro 2020, as illustrated in Figure 1. The model was uploaded to the REXView website to generate QR codes, which were printed on letter-size (8.5" x 11") white paper. When scanned in real time using a mobile device, Samsung tablet, these codes displayed the 3D model showing the necessary steps for installing a wall plug.

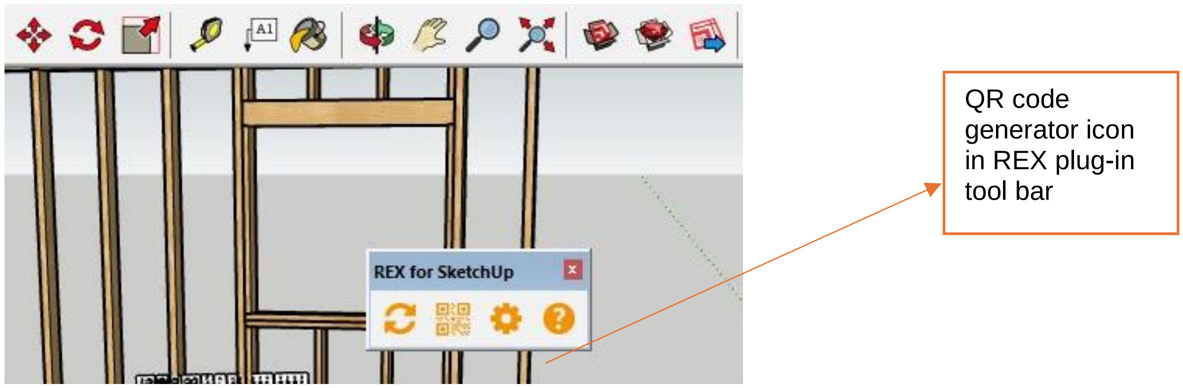


Figure 1: Sample 3D model in SketchUp Pro 2020 window

One can lock the model in place on the screen by tapping on the model. To scale the model up or down, the 1:1 scale icon appears. When selected, the model becomes a life-size model. The model can be rotated, scaled up and down, or moved by the fingers' motion on the screen.

3.3 Pre-test and Post-test Questionnaires

To evaluate participants' experience with the marker-based AR system, both pre-test and post-test questionnaires were administered. The pre-test questionnaire collected information about their demographic details, such as age, gender, and professional background, prior experience with AR technologies, familiarity with electrical installations, and their current mood and enthusiasm for the test. The post-test questionnaire assessed their overall experience using the marker-based AR system, the challenges they encountered during the test, comparisons with alternative instruction methods (e.g., tutorial videos), perceived usefulness for electrical installations, likelihood of recommending the technology to others, and suggestions for improvement. Responses were collected using a 5-point Likert scale (from "strongly disagree" to "strongly agree") for quantitative questions, with additional open-ended questions to gather qualitative feedback.

3.4 Participant Recruitment for Experiments

Upon approval by the University of Houston's Institutional Review Board (IRB STUDY00002581), volunteers were recruited for the test and survey. All participants were above 18 years of age. Nine volunteers participated in the experiment. Participants received orientation training for experimenting regardless of any prior experience they may have had with AR; this was done virtually before the testing date and reviewed again on the test day.

4. DATA COLLECTION

4.1 Work Context

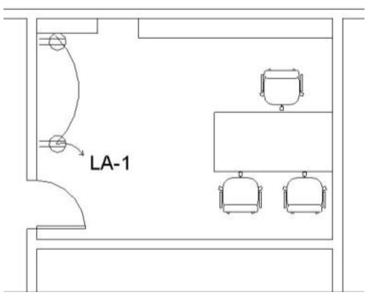
In most cases, electrical installations are carried out using paper-based construction drawings. Metallic conductor (MC) wires and metal boxes are often used in commercial construction for wall plug installations, usually on metal stud framing. Plastic boxes and non-metallic sheet cables, commonly called 'romex' cables, are used in residential construction on wooden framed walls.

4.2 AR-Based Installation Experiment

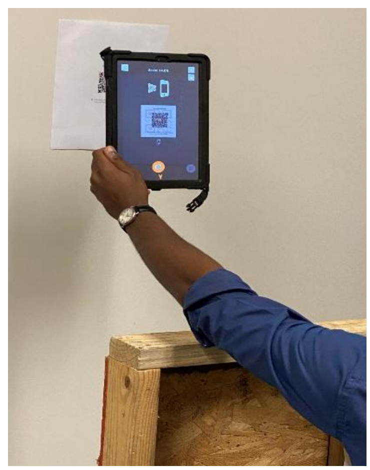
The authors conducted a pilot test using a smartphone, iPhone 11 Pro Max. The pilot test was completed in 30 minutes and 34 seconds. In this case, an MC cable was used. From observations of the pilot test, it was determined that a non-metallic insulated cable (*romex* cable) would be more convenient for the participants. The actual test was carried out using a Samsung Galaxy S6 tablet. Participants completed an online pre-test questionnaire. After completing the test, participants completed a post-test questionnaire about their experience during the experiment.

A mock-up of a wood frame wall, as shown in Figure 2f, was prepared to represent a typical drywall section. The frame had pre-drilled screw holes to receive screws for attaching the metal box for the wall plug. Also, the following items were provided for the experiment: a 15-foot-long Romex cable, a wall plug piece, a wall plug box, and a cover, screws, and cardboard to represent a piece of sheetrock. The installation tools included screwdrivers, masking and scotch tapes, scissors, a cutter, and a measuring tape. The practical test was done in two phases –the Alpha and Beta tests. Beginning with the Alpha test, both tests used a 3D digital model of the wood frame wall created in SketchUp Pro 2020 to display the installation steps.

The model was then displayed on a tablet using an AR program, as shown in Figures 2b and 2d. The data were gathered by recording the total time required to complete the test. Following the Alpha test, a focus group session with seven participants from the test was conducted. Based on input from the focus group session about the model's ability to effectively convey three-dimensional instructions, the model was modified to provide pointer arrows, contrasting (color) backgrounds, and other features that would aid participants in comprehending the steps shown for installing the wall plug. The revised model (Figures 3a, 3b, and 3c) was used for the Beta test with two participants.



a



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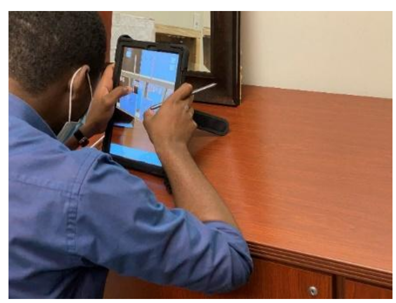
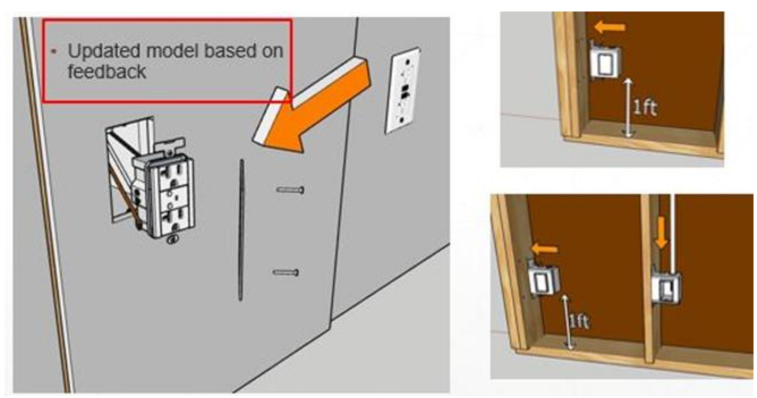


d

e f

Figure 2: Experiment – AR-Assisted Electrical Outlet Installation.
(a) Layout of the experiment area with mock-up frame (LA-1). (b) Participant scans QR code to access the AR model. (c) Tool preparation for installation. (d) Interaction with AR guidance on tablet. (e) Plug installation in progress. (f) Completed outlet installation.

a b



c

Figure 3: 3D Installation Workflow Model. (a, b) Updated 3D mock-up showing six installation steps created in SketchUp Pro 2020. (c) Close-up views of model updates and key installation details.

Time was used as the primary performance indicator for this research. The main activities involved in the experiment are shown in Figures 2a-f. With the experience gathered, a workflow was created to implement marker-based AR, see Figure 4.

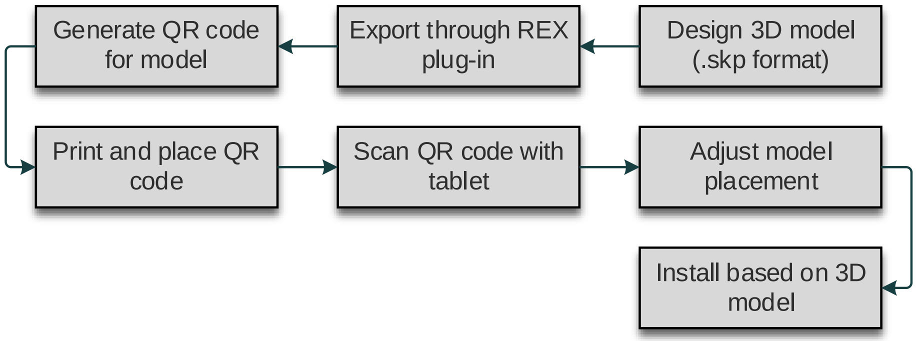


Figure 4: Marker-based AR workflow for electrical installation

5. DATA ANALYSIS

5.1 Industry Survey

The industry survey responses provided insights on the acceptance or awareness of AR among contractors and construction professionals in Houston, Texas, USA. Unfortunately, the authors encountered difficulties collecting data remotely, as contacting many electrical workers, especially those in small construction companies (1-10 employees), through emails or phone calls was difficult. Nevertheless, 17 responses were received, of which 12 identified their companies or organization as electrical contractors, four as general contractors, one as heating, ventilation, and air conditioning contractors, and two as "others."

The survey revealed that 82% of respondents (14 out of 17) had experience with visualization technology in their work, with specific usage including virtual reality (4), Augmented Reality (2), Mixed Reality (1), and other visualization tools (7), while 8 reported using none (see Table 1). This higher adoption rate correlates with company size, as 53% worked for larger firms with over 100 employees (see Table 2). Despite this exposure, 65% used AR primarily for non-construction purposes. Regarding barriers to AR/MR adoption, 30% cited "other" reasons, 30% were unfamiliar with the technology, and 15% questioned its relevance. Nevertheless, 43% (6 respondents) expressed interest in implementing AR/MR, while 50% remained undecided.

Table 1: Visualization technologies used by respondent organizations

Technology type	Number of users among respondents
Virtual Reality (VR)	4
Augmented Reality (AR)	2
Mixed Reality	1
Other visualization technology	7
None	8

*Multiple responses were allowed

Table 2: Organization size of survey respondents by employee count

Size of organizations (employees)	Percentage of responses
1 to 10	24%
26 to 50	6%
51 to 100	18%
Above 100	53%

5.2. Augmented Reality Experiment

5.1.1 Pre-test results of the experiment

The test group consisted of nine participants (7 males, 2 females), with 7 students (78%) and one construction professional (11%). Most participants (67%) had 1-5 years of professional experience and were familiar with AR (78%), with 67% having used AR in various contexts. While 56% had not actively used AR in construction within the past year, the majority (89%) lacked prior experience with electrical connections and wiring. All participants reported positive moods before testing.

5.1.2 Post-test results

The general mood after the test was positive. All participants were impressed with the experiment. Seventy-five percent preferred this technology to watch a tutorial video as 13 percent were indifferent and unsure. Eighty-eight percent felt their student/professional experience positively influenced their performance. Sixty-three percent rated using marker-based AR with QR codes as very good, 25 percent as good, and 13 percent neutral. Seventy-eight percent of the participants felt projecting images of QR codes on surfaces where electrical connections are to be installed would make it easier for them to understand the installation; 11 percent disagreed, while 11 percent more were unsure. Finally, although most participants responded to having challenges in using the mobile device, as shown in Figure 5, all participants responded affirmatively to recommending the use of marker-based AR using QR codes to construction professionals.

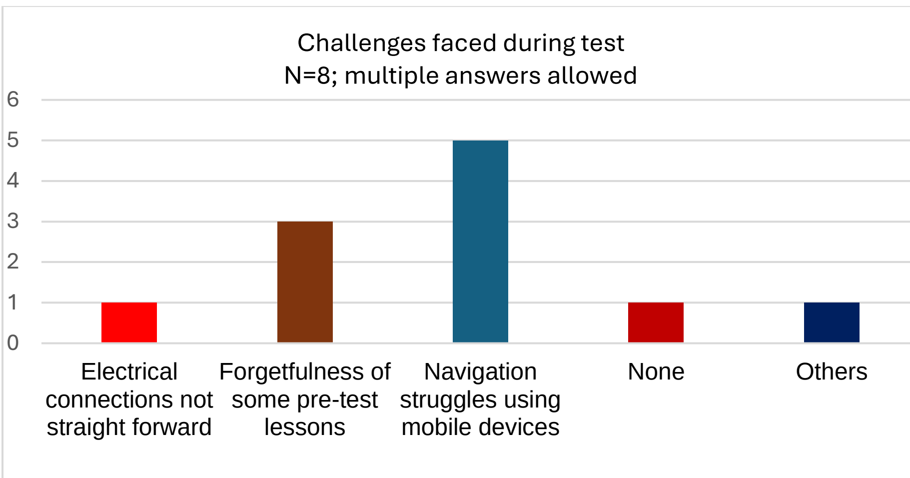


Figure 5: Challenges faced by the participants during the test
(NB: Only eight out of the nine participants responded to the post-test questionnaire)

5.2 Discussion of Results

The industry survey results align with previous studies' findings regarding the limited adoption of AR technologies among small contractors. While Davila Delgado et al. (2020) identified cost as a primary barrier to AR implementation, the survey revealed additional concerns specific to electrical contractors, including uncertainty about the technology's applicability (15% of respondents) and training requirements. This suggests that addressing the knowledge gap about AR applications is as important as reducing implementation costs.

The experimental findings support Chalhoub and Ayer (2018) conclusions that AR can significantly improve design comprehension for electrical installations. However, while their study utilized expensive head-mounted displays, our marker-based approach achieved similar positive user experiences using more affordable and accessible mobile devices. This represents a significant improvement over current practices, which rely primarily on paper-based drawings or video tutorials that lack the spatial context provided by AR.

The time reduction observed between our Alpha and Beta tests (from 30+ minutes to approximately 21 minutes and 15 seconds) demonstrates that well-designed marker-based AR can improve efficiency in electrical installations. This efficiency gain could translate to measurable cost savings for small contractors, particularly when multiplied across numerous similar installations on a project.

Despite some usability challenges with mobile devices, participants' unanimous recommendation of marker-based AR indicates strong potential for adoption if these interface issues can be addressed. The preference of 75% of participants for AR over tutorial videos is particularly noteworthy, as it suggests that marker-based AR offers advantages over current digital alternatives that are already accessible to small contractors.

This study makes several key contributions to both knowledge and practice. It establishes the workflow of low-cost marker-based AR for electrical installations, filling a gap in the literature regarding practical AR applications for small contractors. The implementation workflow developed through experiments provides a template that small contractors can adapt for their specific needs, lowering the barrier to entry for AR adoption. The findings regarding user challenges with mobile devices highlight specific areas for improvement in AR interface design for construction applications. Despite limited prior experience with electrical installations, the positive user response suggests that marker-based AR may have value for training and skill development among newer workers.

6. CONCLUSIONS

To reap the full benefits of AR-based information communication for electrical installations, 3D models must contain comprehensive data. The experiments revealed that certain SketchUp features (dimension strings, 2D lines, and image inserts) did not appear in the AR view, indicating that all elements for AR visualization should be modeled in 3D. The authors developed an implementation workflow for marker-based AR in electrical installations based on our testing. Performance improved significantly when using more detailed 3D models. While the Alpha test with less detailed models averaged over 30 minutes (shortest time: 21:44), the Beta test with enhanced models averaged 21:15. This improvement demonstrates that properly designed marker-based AR can effectively communicate installation instructions and positively impact productivity.

The survey results revealed that despite construction professionals' awareness of AR technology, adoption remains limited, especially among small contractors. However, all test participants recommended marker-based AR for construction professionals, indicating strong potential for broader implementation.
Key challenges identified include the inconvenience of holding mobile devices during installation work. Future innovations should focus on developing mounting systems to affix tablets or other handheld devices to wall frames or surfaces during installations. Also, marker-based AR could significantly benefit building permit departments by streamlining processes and enhancing accuracy. This research demonstrates that marker-based AR using mobile devices provides a practical, cost-effective alternative to expensive head-mounted displays for enhancing design communication in electrical installations, making advanced visualization technology accessible to smaller contractors.

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