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Framing the Scene: An Examination of Augmented Reality Head Worn Displays in Construction Assembly Tasks

Eric T. Bloomquist* Virginia Tech
Joseph L. Gabbard Virginia Tech
Kyle Tanous Virginia Tech
Yimin Qin Virginia Tech
Tanyel Bulbul Virginia Tech

ABSTRACT

The aim of this work is to examine how augmented reality (AR) head worn displays (HWDs) influence worker task performance in comparison to traditional paper blueprints when assembling three various sized wooden frame walls. In our study, 18 participants assembled three different sized frames using one of the three display conditions (conformal AR interface, tag-along AR interface, and paper blueprints). Results indicate that for large frame assembly, the conformal AR interface reduced assembly errors, yet there were no differences in assembly times between display conditions. Additionally, traditional paper blueprints resulted in significantly faster assembly time for small frame assembly.

Keywords: Augmented Reality, Augmented Reality Assembly, Head Worn Displays.

Index Terms: Augmented Reality—User Interface

1 INTRODUCTION

Construction workers performing on-site assembly tasks must refer to information deliverables (e.g., blueprints) to obtain necessary building specifications that facilitate material identification and placement, provide information on workplace standards, and aid in determining order of assembly. Yet the prevailing format used to present information deliverables on-site are two-dimensional (2D) [1], which have been suggested to have a negative impact on task performance when compared to three-dimensional (3D) formats [4]. However, when 3D formats are utilized on-site, they are often rendered on digital tablets or monitors. Not only does this add an extra artifact for workers to handle during task performance, 3D models presented on 2D digital displays does not entirely resolve the issues relating to workers' need to mentally transpose complex information from a model into the environment. Thus, one proposed method for viewing and presenting 3D deliverables is through the use of AR.

Previous research suggests the presentation of assembly instructions via AR HWDs results in faster assembly times and fewer assembly errors compared to 2D presentation methods [2]. Moreover, registered AR instructions that present spatially overlaid information onto workpieces have shown to reduce error rates and mental workload [3]. However, few studies attempt ecologically valid assembly and instead use abstract representations of assembly tasks such as toy blocks. While small-scale assembly tasks can still represent complex assembly processes, one concern is the use of smaller items results in a smaller area in which registered AR cues are rendered. Real-world assembly tasks performed on a construction site would require registered AR cues to be rendered on a larger scale, and outside the AR HWDs field of view.

* email: erictb7@vt.edu

The primary focus of the presented study is to explore the effectiveness of using AR HWD to present building information deliverables across varying scales of real-world assembly tasks. Our work expands upon previous literature by examining to what extent the benefits of AR seen for small scale assembly apply to ecologically valid, large-scale assembly tasks. Additionally, our findings identify unique AR interface characteristics that support worker performance for different scales of assembly tasks.

2 AR APPARATUS AND VISUAL STIMULI

We compared two AR interface conditions, depicted in Figure 1, for presenting *frame blueprints* (i.e., lumber dimensions and layout) to a traditional paper blueprint. AR interfaces were created using Unity3D game engine and rendered using a Microsoft HoloLens One. The *conformal* condition (i.e., world-fixed AR interface), presented virtual 3D graphics directly in the environment such that the placement of actual lumber corresponds with its' virtual representations of the frame blueprints. The *tag-along* condition (i.e., body-relative AR interface), displayed a virtual 2D window that contained a 2D image of the frame blueprint – the same 2D image used for the paper condition. The tag-along display was positioned to avoid blocking participants' view of the environment (1.5 meters from and 0.3 meters above the Microsoft HoloLens). To view the tag-along blueprints, participants had to glance slightly upwards.

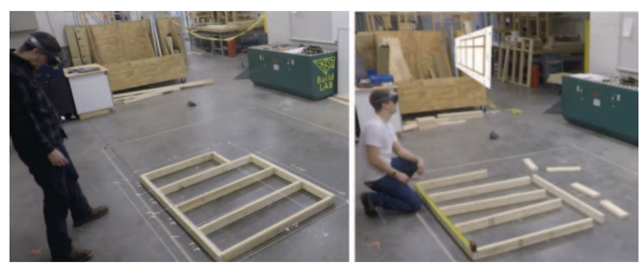

Figure 1: Participants assembled wooden frames using conformal AR (left), tag-along AR (right), and paper blueprints (not shown).

3 METHODS

We conducted a user study with eighteen student volunteers (17 men, mean age = 23.765, SD = 4.480; 1 female, age = 18), all of whom were screened to have relevant experience working on a construction site and operating a nail gun. The study was a 3x3 between-subjects design that manipulated both *display condition* (conformal, tag-along, paper blueprints), and *frame size* (small, medium, large; Figure 2). For each experimental session, participants performed three assembly tasks where they experienced a different display condition and frame size. Display condition and frame size were individually counterbalanced so that all combinations between conditional levels occurred equally across participants. Quantitative measures of task performance included total assembly time and number of assembly errors. To understand participants' opinions and preferences for display conditions, a semi-structure interview was conducted after the study session.

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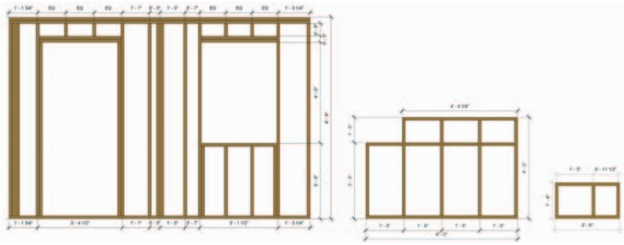

Figure 2: We designed blueprints for each of the large, medium, and small frames. The small frame fits entirely within the FOV of the HoloLens, assuming a 1 meter working distance. Dimensions of the medium and large frame were about three and six times the length and height of the small frame, respectively.

4 Results

To examine the influence of display condition on task performance, total task time and assembly error measures were descriptively and statistically investigated. A two-way ANOVA indicated there was a significant interaction effect of frame size and display condition on total task time ($F(4, 53) = 3.436$, $p = 0.016$). As expected, frame size had a significant simple main effect on total task time ($F(2, 53) = 70.170$, $p < 0.0001$), however display conditions did not ($F(2, 53) = 0.194$, $p = 0.825$). Due to noticeable trends in total task time across frame size (Figure 3), we performed post-hoc contrast tests with planned comparisons among experimental conditions with Bonferroni corrections for multiple comparisons. Results indicated mean assembly time during small frame assembly was significantly faster for paper blueprints ($M = 301.167$, $SD = 78.068$) than the tag-along ($M = 600.5$, $SD = 231.875$) ($p = 0.021$), but paper was not significantly different than the conformal ($M = 415.833$, $SD = 162.167$). Due to a floor effects in our data, we decided against statistically analyzing assembly error data, but rather view them descriptively (Figure 4).

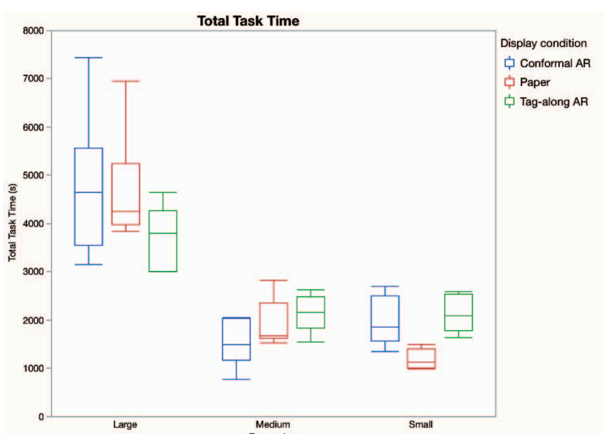

Figure 3: Presents box plots of total task times associated with frame size and display condition.

4.1 Qualitative Measures

From semi-structured interviews (n=16), we found that 75% of participants preferred either one or both AR interface conditions over paper. 38% mentioned that conformal AR aided in selecting correct lumber and 38% stated they used the conformal AR graphics to ensure lumber was correctly laid out before nailing. However, 50% mentioned the overlaid 3D graphics cluttered their view and was distracting while nailing lumber together. Interestingly, a limitation for the tag-along AR was specifically related to the large-wall, where 25% of participants mentioned it was difficult to perceive details due to the large quantity of visual information presented in a small footprint (i.e., the tag-along).

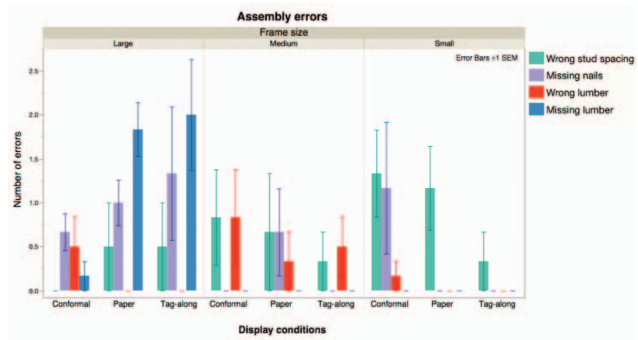

Figure 4: Average of assembly errors that occurred for each combination of display condition and frame size.

5 Discussion

Findings from our study suggest that certain characteristics of different AR interfaces are beneficial for various sizes of assembly tasks. For example, comparing assembly times for the small frame assembly task, we found that using paper blueprints resulted in significantly faster assembly times compared to the tag-along, but not significantly different than the conformal. A potential explanation for our finding could be that users do not benefit from AR when the difficulty of an assembly task is low [5]. For the large frame assembly, our results indicate that using the conformal reduced the number of missing pieces of lumber. Although not statistically evaluated, conformal AR was the only condition that resulted in zero stud spacing errors for large frame assemblies. These findings are supported by previously mentioned qualitative findings regarding the conformal AR graphics assisting participants' perception of the overall frame layout prior to nailing. While our findings suggest that AR interfaces displaying building information can be beneficial during large assembly tasks compared to small, and arguably, more simple assembly tasks, future studies should be conducted to further explore the use of AR interfaces to facilitate various scales of assembly tasks as well as to understand potential impacts on cognitive demands.

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