# Augmented Reality as a Tutorial Tool for Construction Tasks

## Wood frame wall assembly supported by smartphones

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***Abstract*— Augmented Reality (AR) applications mix, by means of display devices, real world environments with virtual objects in real time. The use of AR as a support for the implementation in the construction industry is still narrowly explored. This study proposes the applicability of AR, using smartphones, to aid wood frame assembly. This research innovation proposition is the developing assembly guidance in AR, displaying a wood frame wall model in real scale through smartphones screens. An investigative approach about the possibilities of such integration is proposed and developed, including the development of a specific application. User experience evaluations were conducted. In the evaluation, the participants experienced AR in order to assemble a wood frame wall panel. After that, the participants answered a questionnaire to ascertain the profile characterization and the user experience quality. The results obtained indicated that the proposed system is a useful tutorial tool. From a technology innovation perspective, this initiative has the potential to benefit the application of AR as training and technology support for construction processes.**

***Keywords - Augmented Reality; User Experience; Assembly; Civil construction.***

## I. INTRODUCTION

Augmented Reality (AR) applications associate through visualization devices, real environments with virtual objects in real time. Unlike Virtual Reality, that completely immerses the users in a synthetic environment, AR allows them to look at virtual models superimposed onto the physical world. By merging a range of digital and physical media, AR can be enriched by different perceptions and comprehensions offered by both physical and virtual environments.

Currently, there are few in-depth studies that assess and evaluate human factors and interaction in mobile AR systems [1], especially researches concerning Architectural, Engineering and Construction applications. There is a lack of formal studies concerning the user experience in mobile AR systems [2]. The limited understanding of human factors, which are the basis for interaction with AR systems, can be an obstacle to the diffusion of this technology beyond the laboratory prototypes [3].

As a tool to assist visualization, AR has the potential to contribute to the construction processes as it can exhibit additional information that enables better comprehension and it can also gradually guide the execution. Additional information associated with virtual models can be used if connected to the real construction elements and visualized in AR. This way, AR can provide a visualization of the assembly procedure in an interactive way at the same time it shows superimposed models onto the real world.

The wood-frame construction method combines commitment to the environment with new construction techniques. Considered as a sustainable and dry technology, around 95% of the residences in the United States of America rely on the aforementioned technology [4]; however, in Brazil its adoption is still incipient. The embracement of new construction technologies, like wood framing, depends on individuals' training to develop and execute projects that involve such technologies. Hence, it is important to highlight that new competences must be gained and applied to the work. By allowing individuals to be aided in the assembly process of wood frame edifications, the AR technology would act as a facilitator to the diffusion of this structural system.

The issue that leads this research is if and how AR could be used as a tool to assist the assembly of wood frame panels. The proposal is to convert the assembly steps and way of execution into visible and explicit images through an AR system. In this case, it is important to ensure a suitable user experience while using the AR interface. Therefore, this paper describes a User Experience (UX) evaluation of an AR application using smartphone, to assist a wood frame wall assembly.

This paper is organized as follows: section II explores the state of the art about the user evaluation of AR interfaces; section III presents the developed application; section IV describes the conducted evaluation; section V contains the results and discussion and the conclusion is presented in section VI.

## II. USER EVALUATION OF AR INTERFACES

Traditional directives to evaluate the user interface cannot be exclusively used in this emerging field [1][5]–[7], since AR systems differ from desktop systems in various

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aspects; the most crucial is that such systems are produced for being used as a mediator or amplifier of human visualization [5]. An AR system is, in its ideal form, made to be transparent and more as part of the system of human perception than a separate entity of it [5]. In order for this to happen, the user should perceive the reality with added information and interact with the system in a natural way.

As pointed by [3], there are a number of challenges and difficulties as the hardware (e.g., display resolution, screen brightness and contrast, field of view, device weight) and the software (e.g., accuracy of the tracking algorithms, robustness, ease of calibration) that need to be overcome when evaluating user performance in AR systems. One interface of AR includes hardware, software, interface elements (e.g., menus, icons), markers, interaction techniques (e.g., mouse control, bare-hand interactions) and the content shown in AR. Depending on the device, the tracking form, the interaction technique used, the AR interface is altered. These factors may justify, in part, the lack of standard methods to evaluate AR interfaces.

According to [1], most AR user evaluations fit into one of the four categories: (i) human perception and cognition; (ii) user task performance; (iii) collaboration between users; (iv) system usability and system design evaluation. Among the research that studies user task performance, it is possible to mention a few related to this, as in [8]–[12].

Some researches aimed the consolidation of AR for assembly in the construction field [8][9], targeting the comparison between paper-based and AR manuals as guidance to the assembly; the former used as model a LEGO robot and the latter, a piping system. The results of both researches showed that the use of AR reduced significantly the operator's cognitive workload, as well as the amount of assembly errors and execution time. In [8], one can observe that the AR assembly manual lowered the learning curve of users. In [9], the use of AR proved to be suitable as guidance to trainees in the execution of highly complex tasks, in which training time is limited and errors can be either dangerous or costly. Corroborating, [9] showed that the use of AR proved productive, since it promoted savings in two-thirds of the expenses of correcting erroneous assembly.

Some researches have explored assembly with bare-hand interactions using AR [10]–[12]. In these researches, the users assemble a virtual model, which is projected through a Head Mounted Display (HMD). The virtual objects are manipulated by the movement of the thumb tip and index fingertip. Lack of realism was classified as a limitation, since the assembly is merely virtual and the models and their joints are simple. In [11], disregarding the weights of the elements contributed to the lack of naturalness and realism when handling virtual objects. Also, in [10][12], it is pointed the need to improve the level of realism through a more sophisticated algorithm for joint recognition, thus more complex models could be tested using this system.

While [8][10]–[12] dealt with the assembly of small dimension models, this research explored the assembly of a real size wood frame wall panel, hence, the assembly of a large dimension model. In [9], the assembly of a real size piping system was explored, although the visualization was provided by an external projection, while in this research it happened through the smartphone screen. Thus, this represents an innovation concerning the proposed use of AR and the way it can be used.

## III. AR APPLICATION

A system that could assist the assembly of a wood frame wall structure was idealized. To support this proposal, an application was developed: given a wall and its respective virtual model, an AR application that could put in evidence the execution steps was built up. This stage was developed in three phases, described as follows:

### A. *Wood frame modeling*

In the first phase, a wood frame wall structure was modeled using the Autodesk Revit® software. This structure was idealized to be assembled in laboratory and, for this reason, measures of 1.70 meters wide by 1.75 meters high were adopted. The proposed structure possesses a central opening for window, Fig. 1. Then, the model was exported to Unity 3D software, in which the AR application was developed.

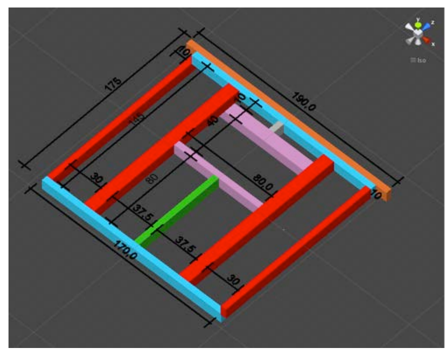

Figure 1. Unity 3D print screen: wall structure.

### B. *Wood components identification*

In the second phase, the eucalyptus components, section 5 x 11 centimeters, were cut in accordance with the project. Each one was identified by color according to its length and function. Thus, the scheme shown in Table 1 was adopted.

TABLE I. LIST OF THE WOOD COMPONENTS (SECTION 5 X 11 CENTIMETERS) THAT COMPRISE THE WALL STRUCTURE

| Length (cm) | Quantity | Color |
|---|---|---|
| 190 | 1 | Orange |
| 170 | 2 | Blue |
| 145 | 6 | Red |
| 80 | 3 | Pink |
| 80 | 1 | Green |
| 10 | 1 | Gray |

Subsequently, the panel was physically assembled. At this moment, the components were drilled in order to offer a pre-set assemble system, Fig. 2. Letters were written to identify elements of the same color to favor its location in the panel. Corroborating, a triangle was drawn on the top of each element to the direction it should be positioned.

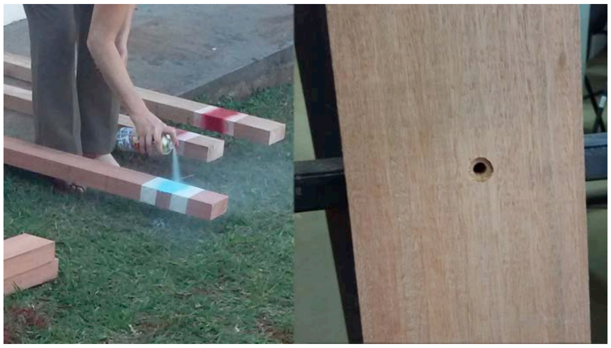

Figure 2. Components identification and drilling setup.

### *C. Application development*

In the third phase, the application functionality, characteristics and development were determined. The "montAR" application was developed from the Metaio's Software Development Kit for Unity 3D. The application was developed to run on smartphones with Android Operating System.

Its functionality is based on the use of a marker associated with the assembly execution steps of the wood-frame panel. The marker is an image with a certain visual pattern that can be recognized by the AR system, which orientates and locates virtual objects in the scene. This marker, when seen in AR, indicates the correct location of the components that comprise the panel by the visualization of the 3D model in real scale, with highlighted indication of its position.

The "montAR" application can be accessed by its icon on the smartphone screen. When running, the application shows a menu with the options: Assemble, Verify and Acknowledgement (in Portuguese: *Montar, Verificar e Agradecimento*). In Assemble, there is a menu on the side numbered from 1 to 7 to access the panel execution steps. These steps consist of exhibition of the AR model elements and also of audio instructions that include the correct positioning, orientation (vertical/horizontal), joints and additional assembly referral, Fig. 3. In Verify, the virtual model in colors is shown, in real size, to facilitate the visual verification of the elements and their positioning on the panel.

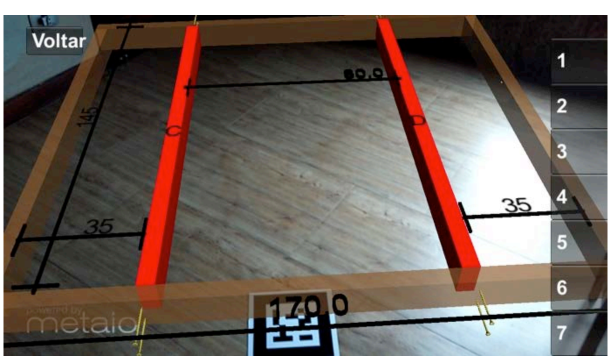


Figure 3. "montAR" print screen: marker, virtual model and the right menu with seven steps

### *D. Application testing*

Once the application was complete, the system functionality was tested. At this moment, its functionality was ascertained and issues such as the positioning and scale of the virtual elements in respect to those of the real ones were verified.

After the testing, alterations were made in order to refine the system, such as in: the execution order, the step-by-step audio instructions, the touchscreen options (drag, spin and enlarge/reduce), the maintenance of the virtual item in the scene even when it is no longer possible to visualize the marker and the insertion of a platform on the floor to favor the use of the screwdriver during the assembly.

## IV. User Experience Evaluation

The purpose of this stage was to assess the quality of the experience of using the system as means of communication of the assembly steps. According to [13], for evaluations that aim to enhance the measurement, such as response time to a stimulus, objective measures are used and, for experiments designed to assess cognitive performance, subjective measures and qualitative analyzes are used. [13] and [14] suggest that evaluations designed to assess cognitive performance are the most indicative of the user experience with the interface and, therefore, subjective measures or qualitative analyzes should be adopted. In this situation, commonly, participants are asked to perform certain tasks. The major advantage of using tasks is that they tend to be more similar to the actions that users would realize with the system. Therefore, the information gained from an assessment of cognitive performance tends to be more relevant and accurate on the application utility.

The assessment process was divided in two sections. The first, being user characterization: age, gender, level of education, frequency of use of smartphone or tablet and previous knowledge of AR systems and wood framing. The second, being the evaluation of the assembly system itself.

Initially, the researcher presented the system by demonstrating its operation and, after that, the user experimented the technology for a few minutes to become familiar with it.

The next step consisted of the task of assembling the wood frame wall structure using the AR application through a Samsung Galaxy S5 smartphone. Thus, a marker was positioned over a wooden platform, which composed the assembly space. The eucalyptus components that comprise the panel, screws, an electric screwdriver and a Phillips screwdriver were disposed alongside the platform, Fig. 4.

 

Figure 4. Provided material for the completion of the evaluation

Following the assembly, a questionnaire was administered to the user in order to assess the quality of his/her experience, which is presented in Table 2. The method adopted was proposed by [14], in which the user experience is classified according to certain characteristics and rated in a Likert scale. To each assertion, the participant would check one of the following alternatives: Totally agree / Agree / Nothing to declare / Disagree / Totally disagree.

TABLE II. UX QUESTIONNAIRE

| | |
|---|---|
| Q1 | The step-by-step provided by the Augmented Reality system to the panel assembly was effective |
| Q2 | I felt that the Augmented Reality system was appropriate to the proposed task |
| Q3 | The smartphone screen size was appropriate to visualize the wood frame panel |
| Q4 | It was comfortable to use the smartphone during the whole time |
| Q5 | The Augmented Reality system interface seemed natural to me (menu, buttons, control and visualization) |
| Q6 | The visualization of virtual information superimposed onto the real world did not confuse me |
| Q7 | When using the Augmented Reality system, I felt encouraged and motived to finish the task |
| Q8 | Guided by the Augmented Reality system, I was able to finish the assembly task at the first attempt |
| Q9 | When I was assembling the wood frame panel, the Augmented Reality system enabled the perception and correction of errors |
| Q10 | I felt that I accomplished the task of assembling the wood frame panel effectively |
| Q11 | I felt satisfied with the way I performed and accomplished the task of assembling the wood frame panel using Augmented Reality |
| Q12 | When using the Augmented Reality system, I felt the desire to continue |
| Q13 | Using this Augmented Reality system made me feel involved in something extraordinary, something new |
| Q14 | I enjoyed the experience of assembling the wood frame panel using Augmented Reality |

a. Based on [14]

In addition to these questions, an open question was provided destined to further considerations, where the participant could comment on his/her difficulties and suggest improvements on the system.

## V. RESULTS AND DISCUSSION

The evaluation involved seven participants, among Architecture and Civil Engineering students, who experimented the AR system through the smartphone screen. The assessment took place on September 2015. The data collected was analyzed aiming the quality of the UX.

Of the total number of participants, three were female and four, male, and all of them were aged between 18 and 24. When asked about the frequency of use of smartphone or tablet, all of them informed daily basis use of this kind of mobile device. None of them had previous experience in any kind of AR system neither had assembled a wood frame panel before.

Initially, the participants were given information about the research aim and explanation on the system operation. All of them took a few minutes to become familiar with the AR functioning.

All of the participants accomplished the panel assembly successfully. On average, each one took 55 minutes to complete the task. Throughout the wood frame structure assembly process, the participants' actions were recorded, Fig. 5.

Figure 5. Documentation of the assembly process

It was observed that while some participants placed the smartphone in their pockets, others laid it down on the board during the execution. It was only removed when accessing a button was necessary in order to move on to the next step, Fig. 6.

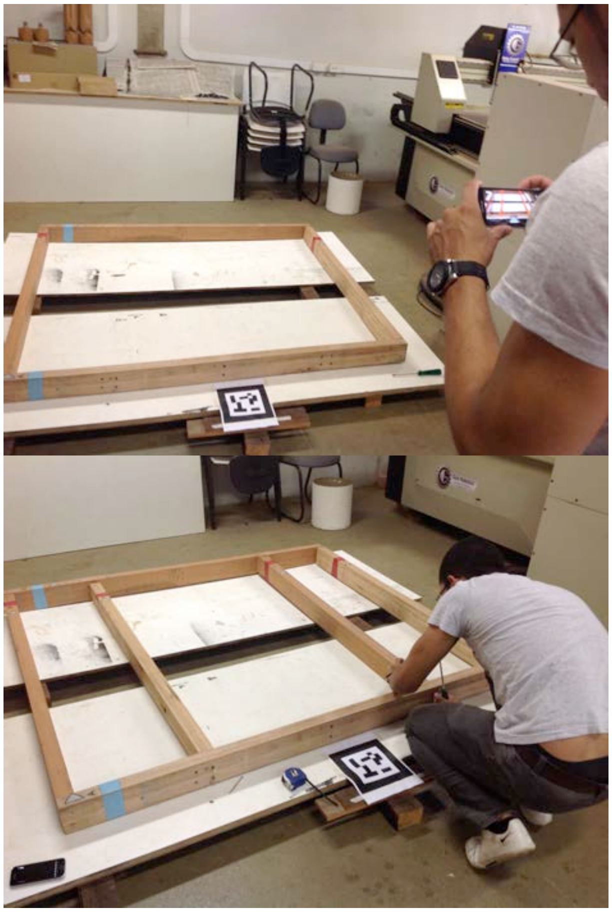

Figure 6. Participant during the assembly task

The results of the questionnaire, in general, indicate acceptance of the proposed system. All agreed that: the step-by-step provided was effective (Q1); the AR system was appropriate to the task (Q2); the screen size offered by the smartphone was appropriate to the task (Q3); the interface provided by the AR system seemed natural to the participants (Q5); they felt encouraged and motivated to finish the task (Q7); they could accomplish the task free of errors at the first attempt (Q8); they accomplished the task effectively (Q10); they felt satisfied with the way they performed and accomplished the task (Q11); they felt the desire to continue using the system (Q12); they enjoyed the experience of assembling the wood frame panel using the AR system (Q14).

On the other hand, three participants declared that the use of the smartphone did not prove comfortable during the whole assembly period (Q4). One participant stated that virtual information superimposed onto the real world caused confusion (Q6); other opted to abstain from commenting about the AR system enabling the perception and correction of errors (Q9) and another did not feel involved in something extraordinary (Q13). Fig. 7 summarizes the answers.

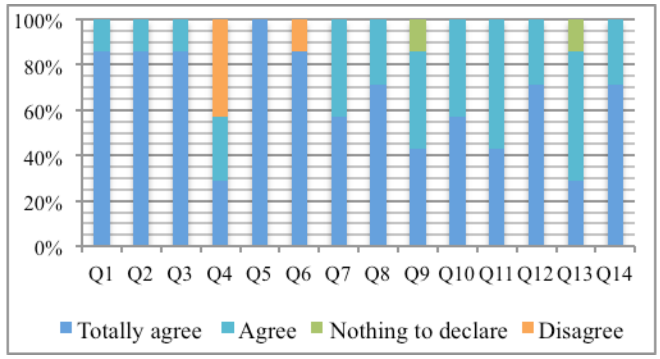


Figure 7. Results from the UX evaluation questionnaire

As warned by [15], the visual disorder may cause ambiguity or difficulty in comprehending the AR content. Corroborating, one participant complained that, at particular times, the superposition of virtual elements over the real ones wasn't accurate. In order to solve this issue, the participant suggested that the virtual elements were more transparent.

One participant suggested the inclusion of one item on the main menu, with initial instructions indicating what is necessary for the assembly, such as screws, wooden pieces, Phillips screwdriver or electric screwdriver. None of the participants, when finished with the assembly, used the "Verify" item from the application. Two participants pointed the need of visualizing the complete model before starting.

## VI. CONCLUSION

In this research, an interactive guide to the assembly of a wood frame wall panel using AR is proposed. Therefore, the use of the virtual model associated with AR technologies, which provide the possibility of interaction between the user and the combination of virtual and real environments, is presented.

To that end, an AR application named "montAR" was developed for smartphones. The application exhibits the assembly process of a wood frame wall structure in an interactive way, in order to facilitate the assembly, even for beginners. The system was developed so that the users could assemble the wall without the need of paper-based manuals.

In order to better understand how "montAR" can be used, this research presents an evaluation of the UX. All of the participants were able to successfully accomplish the task of assembling the wood frame wall panel using the AR system. In general, they indicated the acceptance of the system and seemed interested in the technology.

The system needs further refinement until the application achieves a proper operation to that end. Therefore, improvements must be made in accordance with what was pointed out in the assessment, which are: more transparency to the virtual elements, inclusion of initial instructions to the menu and the option of visualization of the complete model.

The proposition of innovation of this research lies in the fact that this technology is being used here as means of offering a practical tutorial for the execution of the wood frame wall panel. Such initiative holds the potential to benefit people's training in this construction system, which is still incipient in Brazil.

Hopefully, the assembly of wood-frame edifications can be assisted by the development of an application that offers an interactive step-by-step in AR. Therefore, this application can contribute to the diffusion of the wood-framing in the Brazilian construction process, providing its adoption and propagation. The resulting artifact of this research can be used by workers in the construction site as well as Architecture and Construction professionals, teachers and students for teaching and learning.

In a wider perspective, this research indicates that the use of AR can be important for the construction process as a whole, even those which are already consolidated. For this reason, new studies in these terms are essential.

Future work will focus on developing a comparative study between the panel assembly using AR through smart glasses and smartphones. This comparative study will aim to verify which device is more likely to be accepted by the user during the assembly task.

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