Building Owner Manual Assisted by Augmented Reality: A Case from Brazil

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Abstract

The building use, operation, and maintenance manual, also known as the building owner’s manual (BOM), is a document that provides all the information necessary to help Brazilian home owners operate, maintain, and repair their buildings. However, such manuals are in most cases presented in textual format with sparse technical terms and references, and lack the necessary information as required by federal government standards. As a result, building owners often find it difficult to effectively use the manual or find specific content pertaining to the problem to be fixed. A potential remedy to this situation is to enhance the traditional building manual’s format using augmented reality (AR) that promotes new forms of interaction between the user and the BOM. In a nutshell, AR enables the displaying of virtual (computer generated) graphics overlaid on views of the real environment. The specific objective of the research presented in this paper is, therefore, to create and assess new formats of BOM enriched by AR in order to promote its use. To this end, a survey was first conducted and a total of 27 BOM samples were collected from Brazilian construction companies. After a thorough content analysis, one of these manuals was selected and used in the prototype living augmented reality (LAR) application. A graphical software and a game platform are used to develop LAR that can be launched on tablet computers and smart glasses. LAR displays a step-by-step AR animation of a maintenance activity to the user. This paper presents results of the survey of BOM manuals currently practiced in Brazil, as well as a description and technical details of the preliminary LAR maintenance experiment.

INTRODUCTION

A typical project lifecycle includes the design, construction, operation, and maintenance stages. By definition, this philosophy is also applicable to buildings, and thus necessitates the creation and adoption of standards that consider the entire life span of a building. The Brazilian government regulates the building owner’s manual creation through specific guidelines and rules that describe the use, operation, and maintenance of a building. The goal of the Building Owner's Manual (BOM) is to support building longevity and durability not only through an appropriate design and
construction, but also by providing specific information to facilitate proper use and maintenance (CBIC, 2014). Santos (2003) studied several BOMs collected from multiple building contractors and found that the majority lacked useful content. In addition, Aguilera (2005) analyzed the norms and laws in eleven BOMs and found that few companies developed useful BOMs with necessary detailed content for the users, and that the number of people with knowledge in creating such manuals was steadily decreasing. Lourenço Filho (2009) revealed that some construction companies recognize the importance of BOMs, but mainly since the mere inclusion of a BOM can provide a legal protection to them in case of a major problem with the building or its components. This implies that to a considerable number of contractors, the value of the BOM is not necessarily in helping out future occupants to use their facility in the best possible way by providing meaningful information about how to maintain the building.

During the past decade, visualization and information technology have gained increasing credibility in architecture, engineering, construction, and operation (AECO). Rohani et al. (2014) stated that visualization is a powerful tool for managing construction projects. The sub-disciplines within the AECO have a growing tendency to interact directly with the information associated with the building/facility production process. To this end, visualization can be a valuable medium for exchanging such information among project’s stakeholders who have different technical backgrounds and levels of understanding about project tasks and requirements. Augmented reality (AR) is a fast growing visualization paradigm that has the ability to enrich the work environment by integrating multiple information modalities in real time, which is especially useful for manufacturing, assembly, training and maintenance activities (Nee et al. 2012). Several studies have demonstrated the use of AR in assisting decision-making in various stages of construction (Kamat et al. 2011). AR visualization is also a valuable addition to product assembly procedures where high precision and low error rates are desirable (Hou et al. 2014). AR has been also used to demonstrate alternatives design solutions in architecture (Moreira and Ruschel 2015, Yang et al. 2016), as well as a pedagogical tool to teach engineering curricula (Shirazi and Behzadan 2015).

Inspired by previous work in this field, and the existing gaps in knowledge and practice, this paper aims to investigate the current trends in developing BOMs, and assess how these manuals incorporate the recommendations and guidelines of the Brazilian government. At the start of the project, a survey was conducted and a total of 27 BOM samples were collected from Brazilian construction companies. After a careful review, one of these manuals was ultimately selected and used in the experiment in which the textual content describing a building maintenance activity was enriched using augmented reality (AR). This prototype experiment was implemented in Living Augmented Reality (LAR), a mobile AR application that was designed and tested in this research.

**Building Use, Operation, and Maintenance Manuals**

The European Union (EU) legislation specifies that a product is only complete when accompanied by an operations/instruction manual. The product delivery or sale without a manual is against the law and, in most cases the user is entitled to full assistance if circumstances arise. In addition, the distribution of technical products in
the EU requires a conformity declaration. Without a complete and proper manual, if any problem occurs with the product, the distributor must bear full responsibility for the loss (SECUREDOC, 2004).

Since buildings are essentially products that are sold to consumers (i.e. occupants), they must be treated the same in that an accompanying manual should provide necessary information to guarantee the durability of the building and the preservation of its original conditions during its lifetime. However, buildings are among the most sophisticated products that can be built and acquired, and as such, the lingering question is how to develop and present an efficient interface and continuity between design, construction, and maintenance stages in the BOM. To this end, the planning and use of corrective and preventive building maintenance programs are of the essence. This issue becomes even more evident when buildings are more complex (ABNT, 2014).

In Brazil, the Consumer Protection Code or CPC provides for consumer protection requirements and protection standards. Article 50 of CPC describes contractual guarantees that must be followed. These guarantee terms must be standardized and adequately presented to cover all definitions, as well as form, term, place, and consumer's and manufacturer's responsibilities. A product instruction manual must also accompany this information and be delivered in a didactic and illustrated language (CPC, 1990). Moreover, the Brazilian Association of Technical Standards (ABNT) is the official representative of the International Organization for Standardization (ISO) in Brazil is responsible for drafting, approving, and administering the Brazilian standard guidelines (a.k.a. NBR).

In particular, NBR 14037 aims at establishing minimum requirements for content preparation of BOMs. According to NBR 14037, a BOM must, at a minimum, contain sections that describe: (i) presentation; (ii) guarantees and technical assistance; (iii) descriptive building description (a.k.a memorial); (iv) suppliers; (v) operations, use, and cleaning; (vi) maintenance and, (vii) complementary information (ABNT, 2014).

**METHODOLOGY**

The methodology adopted in this work follows the Design Science Research (DSR) approach, also known as “Constructive Research”. This approach is used to simultaneously achieve two different purposes in a research project: producing scientific knowledge, and helping organizations to solve real problems (Dresch et al. 2015).

As previously stated, the goal of this research is to evaluate the incorporation of AR features in the BOM. The specific steps that were followed in this research include: (i) study the principles of BOM and AR; (ii) survey of owners, builders, and BOMs; (iii) analyze and classify Brazilian BOMs, and (iv) propose a new form of BOM enriched by AR. These research stages are illustrated in Figure 1. In this paper, the authors present findings from the survey, BOM analysis, and the prototype maintenance activity experiment carried out in LAR.
SURVEY RESULTS

A total of 27 BOM samples were received and analyzed for conformity with the NBR 14037 recommendations. The collected BOM samples came from all five major geographical regions in Brazil with some builders sending more than one BOM. Specifically, the participating companies represented the South (10 samples), Southeast (8 samples), Midwest (4 samples), Northeast (6 samples), and North (1 sample) regions, as shown in Figure 2. All surveyed companies stated that they always offered BOMs to their clients, indicating that 100% of builders recognized the importance of providing the BOM. As for the delivery format, it was found that the print BOM was the most commonly used type representing 60% of all collected samples, followed by CD/DVD media at 50%. Also, 20% of builders provided their BOMs in other formats such as on memory stick, digital files, and multi-format (e.g. both print format and CD). Interestingly, only 3% of respondents used online tools (i.e. website) to deliver the BOM, while no company used a software (application) to provide BOMs to their clients. As far as the development of the BOM is concerned, it was found that 63% of companies developed their own BOMs, 17% outsourced it, and 20% did both (created some and outsourced the rest).
Next, collected BOM samples were assessed for containing the items recommended by NBR 14037 (i.e. presentation, guarantees and technical assistance, descriptive memorial, suppliers, operations, use, and cleaning, maintenance, and complementary information). A grading system was defined, and a score (complete, satisfactory, and basic) was given to each sample BOM for its compliance with this criterion. A “complete” score means that a BOM scored 66% or higher, a “satisfactory” score indicates a compliance rate of between 33% and 66%, and a “basic” score refers to minimum compliance (i.e. below 33%). Figure 3 shows the distribution of scores received by collected BOMs. In this Figure, “not included” refers to a case in which a BOM completely missed an item. As seen in this Figure, “guarantees” received the highest percentage because the CPC in Brazil mandates the inclusion of this item in the product’s manual. This item covers information such as guarantees, loss of guarantees, and building technical assistance. The guarantee period normally starts from the date the building is delivered, as established in the "Occupancy Permit". Per the CPC, any non-compliance with this item by businesses or homeowners can result in litigation and potential financial losses.

From Figure 3, it is clear that items in the collected BOM samples that scored “satisfactory” include descriptive memorial (67%), and complementary information (52%), and operations, use, and cleaning (52%). Having said that, it can also be seen that operations, use, and cleaning has scored as “basic” with only 48% of the total. The complete category doesn’t exist in 5 - Operation, use and cleaning. It is justified for the different complexity of the buildings. The NBR 14037 recommends that the BOM information be didactic with illustrations, schematic drawings, photographs, and tables. However, during the analysis of the collected BOMs, it was verified that the textual format is the most commonly used way of communicating the BOM information with building owners. In fact, only 11% of collected BOMs contained images and other visual media in addition to textual information.

![Figure 3. Analysis of collected BOMs for conformity with NBR 14037](image-url)
LIVING AUGMENTED REALITY (LAR) PROTOTYPE

In addition to collecting and analyzing sample BOMs, a systematic literature review (SLR) about AR for assembly, maintenance, and building operation was performed. The SLR analyzed 38 journal articles that were published within the last 17 years. The analyzed sample found a late appearance of these applications, specifically in the building maintenance and operation. In addition, SLR results showed that AR has a potential to enhance BOM, and indicated the extensive use of marker tracking in the majority of applications, followed by a growing use of sensors and marker-less tracking. Findings supported the need, thought process, design, and implementation of the LAR prototype as will be described below. The LAR experiment described in this paper shows a maintenance activity as included in one of the collected BOM samples that scored “complete” in the maintenance category (item 6 of NBR 14037). The maintenance activity selected for this experiment is the replacement of the valve toilet component. The AR animation visualized and displayed contains the exact same steps described in the original BOM.

For this animation, as shown in Figure 4, a valve toilet and its components were first modeled in Revit Architecture 2017, and then the model was exported to 3D Studio Max 2017 to add textures. Next, the model was exported to Maya 2015 to create a step-by-step animation in 3D (as described in the BOM). The animation was then exported to Unity 5.5.0f3 with Vuforia 6.2.6 to create and add AR features. All interaction buttons, AR markers, and the user interface were also created in this stage. Finally, LAR was launched on a tablet computer to assist the user by providing visual information about the maintenance activity.

Figure 4. Stages of LAR prototype development

LAR Marker Design

LAR uses marker-based tracking to register and display virtual contents over the views of the real world. The markers used by LAR are designed with “scalability” in mind. In particular, as shown in Figure 5(a), the image at the center of the magnifying glass is a representation of the virtual content that will be visualized in AR. For the experiment described in this paper, the object of interest is a valve toilet and thus, the marker shown in Figure 5(a) is used. The symbol under the magnifying glass identifies the type of activity. For example, Figure 5(a) shows a hammer and a wrench resembling a maintenance activity. With the same token, the marker shown in Figure 5(b) is used to view information about a building wall or facade (image of the wall in the magnifying glass and an eye symbol at the bottom). All markers use the same edges (thick black lines of a mobile phone) which indicates they are designed...
for use with mobile devices. For a marker to be easily detectable by the AR application, it needs to be non-symmetrical and have well-defined borders. The Vuforia developer website has a verification process to analyze marker features. Using this process, the marker image is uploaded to the website and a classification scale is calculated and displayed. The classification scale ranges from one star to five, with one star indicating that the marker is not a good tracker, and five stars implying that the marker is very suitable for tracking. Figure 6 shows the feature points detected by Vuforia, and the 5-star tracking score given to the LAR marker used for the maintenance activity.

![Marker classification and tracking features](image)

**Figure 5.** (a) Marker to fix vase toilet, and (b) marker to view wall information

**LAR Development**

As previously mentioned, the initial 3D model (generic vase toilet with detailed elements) for LAR animation was first created in Revit Architecture 2017.
The generic vase toilet model was selected from Revit library components, and only the internal elements had to be modeled separately to make sure their attributes match the specifications of existing brands in the market. The generated model was then exported to 3D Studio Max 2017 in .fbx format where textures and materials were added. The output was exported in .3ds format to Maya where some last minute texture touch ups were implemented. The resulting animation was finally exported in .fbx format to Unity to create the LAR visualization. In addition, the AR fiducial marker, as well as the user interaction buttons and interface were created in Photoshop. Figure 7 shows screenshots of the final animation as displayed to the user. Each part in this Figure shows a key step in performing the maintenance experiment as also described in the selected BOM. They include: (i) open the top of the toilet vase; (ii) unscrew the buoy; (iii) take the buoy to a hardware store and buy a new one of same size and form; (iv) tighten the new buoy in place using the screws in the exact same manner the old buoy was located; (v) put the top of the toilet vase back in place.

Figure 7. LAR Prototype in use for the toilet maintenance experiment

The LAR prototype was developed with extended tracking features to provide more tracking stability once the marker was initially detected. This allowed the animation to stay and play in place even if the marker was no longer visible, or partially blocked. Extended tracking is very useful especially for visualization of
large objects such as buildings, big pieces of furniture, and architectural artifacts. In order to achieve desired results with extended tracking in the LAR experiment described above, some adjustments had to be made that included the adaption of the marker scale to the model scale, and scaling the 3D toilet vase model beforehand to the real toilet vase size.

CONCLUSIONS AND FUTURE WORK

This paper described the current state of practice in developing and using BOMs in Brazil, as well as presented the design and development of Living Augmented Reality (LAR), an AR-enabled experiment for a building maintenance activity. First, the authors conducted a survey of BOM samples collected from five geographical regions in Brazil, and found that while all surveyed construction firms (100%) provided BOMs to their clients, only 63% developed their own BOMs. It was also concluded that most companies still used the print version of the BOM as the main delivery format, and only few companies used online tools (e.g. the internet) to publish the information. In studying the collected BOMs, it was noted that contents pertaining to guarantees and technical assistance were the most complete of all items mainly because the inclusion of such contents is mandated by the Brazilian CPC. In addition, it was evident from the analysis that different parts of the BOM did not receive equal attention by the builders. For instance, content pertaining to maintenance and repair could be significantly improved with greater attention to detail in most of the analyzed BOMs.

Survey findings motivated the design and development of LAR, an AR-enabled visualization interface designed to assist in building repair and maintenance. In particular, LAR was used to enhance the textual content of a BOM by providing step-by-step visual guidance to the user during a toilet maintenance activity. The feedback collected from a builder who tested the developed AR prototype application was very positive, as he wrote “most owners no longer use the traditional print BOM, and LAR offers an alternative solution with a high level of detail. It is very helpful for owners to understand their buildings and not to judge the builders for anything bad that happens in the building. Owners should know how to maintain their buildings. LAR is very useful.” For future work, the existing functionalities of LAR will be enhanced by providing users with more visual contents. Also, a more comprehensive pre- and post- analysis will be done to systematically assess the benefits of LAR over the traditional print BOM. The authors also plan to test LAR using smart glasses, collect user performance data, and improve the graphical interface and interaction features accordingly.

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REFERENCES


