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# AUGMENTED REALITY SUPPORTING BUILDING ASSESMENT IN TERMS OF RETROFIT DETECTION

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## ABSTRACT

Post-occupancy evaluation (POE) is a systematic and rigorous process to evaluate the built environment after it has been occupied for some time. This process, in addition to identifying user satisfaction, building performance and pathologies, can also reveal building retrofits made to adapt to the users' requirements or change of function. Traditional data collection for retrofits detection is made with questionnaires; depends on user memory and disciplined observation by the researcher of the built environment in comparison to original design. Therefore, if POE for retrofit detection is less based in users' memory and more based on accurate observation, this could represent more efficient results. Augmented Reality (AR) enables this possibility since it allows to overlap the visualization of the real site with its virtual model, then researcher can identify the modifications made in buildings as elements of the site that do not exist in the virtual model. Therefore, with AR the comparison between what was designed and what is constructed becomes more visual and less dependent of subjective factors. Traditional POE process model involves three phases: planning, conducting and applying. In order to incorporate AR it is proposed a total restructuring of the planning phase, developing the research instruments in three steps: 3D modeling, model treatment and AR application development. It was observed that for POE studies the 3D models are in large scale and need to be detailed for precise comparison. BIM models for facility management, representing building use situation, are of the highest level of detail (LoD 500). A balanced point between simplicity and representativeness was the solution adopted in this experiment for upload and download performance issues. This article presents and discusses findings for the new proposition for the activity of research instruments development for the planning phase of POE with AR as well as initials tests with first results and difficulties faced.

**Keywords:** Augmented Reality, AEC, POE, BIM model.

## 1. INTRODUCTION

Augmented Reality (AR) can be summarized as a technology that uses Virtual Reality (VR) to add virtual objects to real environments in real-time, using technological devices for the visual overlapping of images (Azuma, 1997; Höhl, 2009; Kirner et al., 2004). Virtual Reality is known as a technology that adds the dimensions of immersion and interactivity to three-dimensional computer generated models and offers an exploration that is not viable with the traditional form of representation (Burdea, Coiffet, 2003, p. 2). In architecture and construction these technologies can assist in the design and visualization of architectural forms, results of simulation and analysis of energy issues as well as in the manufacturing of structural components or directly in the construction, for example, at the construction site or during Post-Occupancy Evaluation (Amim, 2007).

Messner (2008) suggests the application of VR/AR to visualize and interact with design information during construction. Infrastructure design is augmented during construction progress from the start of site layout design

motivating construction innovation. The overlapping of virtual elements allows technicians, with AR, to anticipate vision of construction over site with details of design, including the 3D model of the finished building.

AR is in constant evolution and has been facilitated with the development of portable equipments, which allow the visualization of virtual objects in real time in mobile manner. Another improvement is the increased availability of programs for the development of AR applications.

Within this context, mobile AR can support agents responsible for technical reviews of buildings performing Post-Occupancy Evaluation (POE). AR may allow more accurate perception of the interventions made by the residents, collaborating with the adjustment of future developments. POE is a systematic and rigorous process to evaluate the built environment after it has been occupied for some time (Preiser, Rabinowitz, White, 1988). This process, in addition to identifying user satisfaction, building performance and pathologies, can also reveal building retrofits made to adapt to the users' requirements or change of function. Retrofits done by residents reveal important aspects and values that may be incorporated into the design process of new buildings of the same type. Traditional data collection for retrofits detection is made with questionnaires; depends on user memory and disciplined observation by the researcher of the built environment in comparison to original design. Therefore, if POE for retrofit detection is less based in users' memory and more based on accurate observation, this could represent more efficient results. Thus, AR may represent this gain by applying its resources for identifying reforms. The Building Information Model (BIM model) visualized against the real constructed and used building could be used in this situation. It is a promising solution to improve the state of the art in visualization in architecture, design process, construction processes and facility management, emphasizing POE.

This articles presents the use of mobile AR system for tablets supporting POE. The aim is to improve retrofit identification while walking through the existing built environment. A research is presented where AR is tested in POE situations for low income housing. The study is developed in the city of Campinas, in the state of São Paulo – Brazil.

## **2. GROUNDINGS**

### **2.1 Post-occupancy evaluation and low incoming housing**

Preiser, Rabinowitz and White (1988) orient that the focus of POE should be on the occupants of the buildings and their needs, in order to give evaluators the perception of the consequences of decisions taken during the design and its results in terms of performance and attendance to user needs. The main objective of this type of study is to provide knowledge based on real facts that allows the design of more suitable buildings in future projects. Ornstein (2007) complements that POE is as a set of methods and techniques applied during the use the built environment for evaluating performance, both from the perspective of the user as well as of experts, systematically indicating positive and negative functional aspects. It evaluates aspects such as construction system, environmental comfort, maintenance cost and also the relationship between the built environment and human behavior.

In terms of dwellings designed and constructed for the low-income population, that is social housing, it is noted that the projects do not always meet users expectations. This fact in Brazil, along with the lack of urban infrastructure, creates dissatisfaction and causes structural, functional or aesthetic user interventions in housing, in the search for a better quality of life (Bittencourt, Silva, 1996; Kowaltowski, 2005). POE collected data is in the form of numbers, text, images, drawing and recordings. The visualization of results are usually indirect in the form of tables, graphs and schemas. Therefore, the use of technological resources to facilitate design feedback can mean a step forward in the search for improvement of future construction, using such information. In this sense is that the use of AR can make the process of POE faster and better understood by technical agents that make the evaluation of housing, allowing also the improvement of the presentation. The visualization of that which was designed and built in opposition to what was desired and changed by the user (the reforms made) is what makes this technology feasible for improvements in the identification and registration of retrofits in POE. Thus, the result ceases to be text only, becoming visual and comprehensive. This research aims to associate a new technology to the process that is already established, however, not widely used by professionals from the architecture and construction.

## 2.2 Mobile Augmented Reality

With although smaller but powerful computers, new mobile applications emerge combining technologies such as: global tracking, wireless communication and location-based services; allowing AR possible to be used by anyone and anywhere (Höllerer, Feiner, 2004). An example is Thomas, Piekarski and Gunther (1999) early proposition of mobile AR, where the users wear the computer and uses a see-through HMD, allowing to move freely and with correct location through the technology of GPS (Global Positioning System) (Figure 1a).

With the rise of tablets and Smartphone equipped with GPS, wireless or 3G/4G communication, AR became more versatile (Rösler, 2009). These devices combine the processing power, memory, interaction technology, GPS and digital compass, and integrated cameras that allow viewing of built environment and with real time mixing of virtual objects (Bimber, Raskar, 2005) (Figure 1b). With the ability of these mobile devices and simplification in terms of hardware, there is a possible increase in the range of potential uses for AR (Cuperschmid, Freitas, Ruschel, 2012). AR applications have been developed for tablets and smartphones, for multiple uses: entertainment, guides and education are some examples. These applications apply constantly evolving technology, especially in the case of applications developed for use over the Internet.

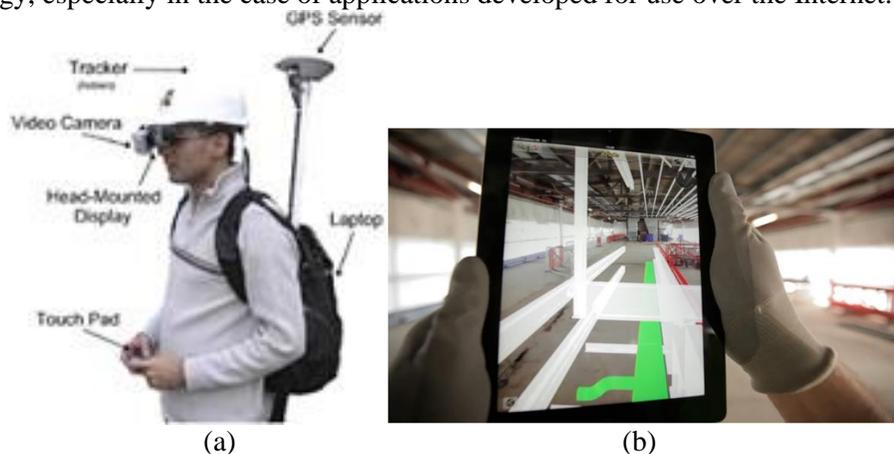


Figure 1: (a) Basic hardware components of a system of mobile AR (Behzadan; Timm; Kamat, 2008, p. 91) and (b) mobile AR with tablet<sup>1</sup>

Figure 1b shows an example of similar use for AR in civil engineering as proposed in this study. Bechtel, an engineering company, uses Junaio with Autodesk 360 Mobile to superimpose virtual layout of mechanical, electrical and plumbing systems on real site images of the construction. In this case, the positioning is done by georeferencing the model to site location.

## 2.3 Building Information Modeling (BIM)

According to Succar (2009), Building Information Modeling (BIM) is an emerging technology and requires a procedural change for the sectors of Architecture, Engineering, Construction and Operations (AECO). Eastman et al. (2008) define BIM as a modeling technology and associated processes to produce, analyze and communicate information with information models of buildings. Since the building information model must be reused by different agents in different situation throughout the building life cycle, these agents may input the information model in varying computer programs. This results in model transformation, therefore interoperability is essential. Interoperability allows improved collaboration and is achieved when there is no or low loss of information from the reuse of the information model. There are many ways to achieve interoperability (Jardim-Gonçalves, Grilo, 2010; Nour, 2010; Halfawy, 2010), one way is the OpenBIM. OpenBIM “is a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows.”( <http://www.buildingsmart.org/openbim>). OpenBIM promotes the use of an open data model

<sup>1</sup> <http://www.apple.com/ipad/business/profiles/bechtel/>

developed as common data schema (IFC) that makes it possible to hold and exchange relevant data between different software applications.

The evolution of a BIM model are described in the level of detail (LoD) from the lowest level in the conceptual phase, gradually increasing in level of accuracy and representation for the construction phase, manufacture and operation (Bedrick, 2008). The level of detail for a BIM model must correspond to the needs of the modeler, the project engineer, and the estimators and schedulers (<http://www.vicosoftware.com/BIM-Level-of-Detail>).

LoD also corresponds to Level of Development (American Institute of Architects, 2008) establishing the requirements for model content at five progressive levels of development, and the authorized uses of the model content at each level of development. These levels of development are: LoD 100 for overall building massing, LoD 200 for generalized systems or assemblies, LoD 300 for specific assemblies accurate in terms of quantity, size, shape, location and orientation, LoD 400 for specific assemblies with complete fabrication, assembly, and detailing information and LoD 500 for constructed actual assemblies.

Leite et al. (2010) observe that there is a great interest in research related to the use of information models, but few investigate the effort required to generate the model in different LoDs and their impact on design.

LoD of BIM models affects use in mobile AR because 3D content must be uploaded and rendered in real time though the Internet and BIM model's LoD interfere in the model file size, consequently, in the data transmission on the web. The simplification of 3D content for upload and download performance issues is required in this case and a balanced point between simplicity and representativeness should be found for the model. The LoD of the model itself may not change, but it has to be filtered to determine the final file size.

### 3. RESEARCH METHOD

The POE process model proposed by Preiser, Rabinowitz and White (1988) is adopted, involving three phases: planning, conducting and applying (Figure 2). In order to incorporate AR it is proposed a total restructuring of one activity of the planning phase, that is, the development of research instruments. It is foreseen that other activities proposed by Preiser, Rabinowitz and White (1988) for this initial planning phase does not change due to the use of AR, therefore are maintained. The second phase of a POE is the conducting phase, which includes on-site data collection process, monitoring and managing data collection and finally data analysis. Since instruments for data collection are totally different, this phase needs total rearrangement.

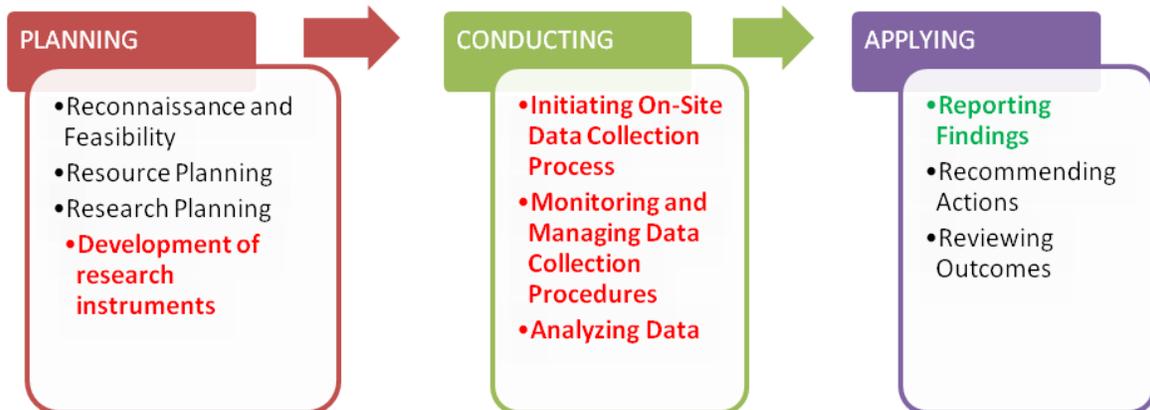


Figure 2: POE process model proposed by Preiser, Rabinowitz and White (1988) indicating activities which will be adapted (in red) and used for analysis (in green)

In order to evaluate the effectiveness of the use of AR for retrofit identification two POE studies are been developed and will be compared. The study is under developed for an existing social housing development (CDHU Campinas-F) in the city of Campinas, São Paulo, Brazil (Figure 3). The studies will differ in the following manner: one will be developed with the traditional process model proposed by Preiser, Rabinowitz and

White (1988) and the other will be developed with this process model adapted to the use of AR (Figure 4a). Report's findings extracted from the applying phase of these studies will be compared.



Figure 3: Aerial and street view of the social housing Campinas F – CDHU

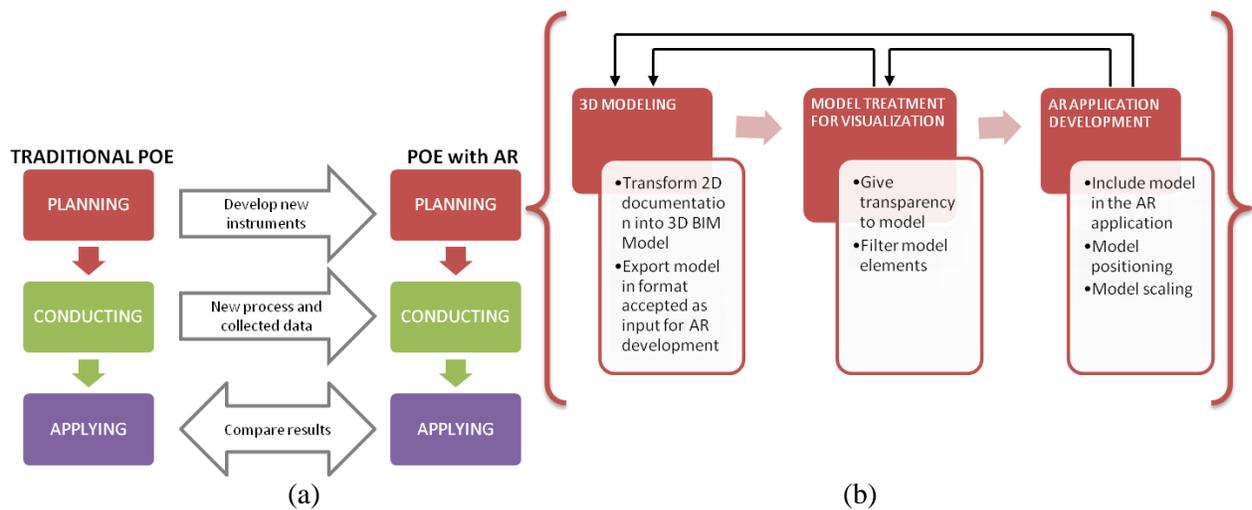


Figure 4: Relation between the two POE studies in development and detailing of transformation of the activity of research instrument development in the planning phase of POE with AR

This article presents and discusses findings for the new proposition for the activity of research instruments development for the planning phase of POE with AR (Figure 4b). This activity is proposed to be developed in three steps: 3D modeling, model treatment and AR application development. 3D modeling starts from 2D drawing because the design of the social housing in study was developed using this kind of representation. A BIM model is developed and exported to a data format accepted as input in application available for AR development. The model must be treated in order to obtain transparency and therefore allow visualization of superimposed objects (real x virtual). The model must also be treated in order to become lighter and simplified, to enable its use and manipulation in selected mobile AR application. Finally, the treated model is incorporated in the mobile AR application, instantiated for the site in study, requiring model positioning related to the site and scaling.

#### 4. DEVELOPMENT

The results of the activity of research instrument development in an AR application associated to a specific built environment. This application is downloaded, installed in a mobile device and used in site by the person in charge of data collecting. The data collecting comprehends two possible situations: searching for user intervention (retrofits) on open space (outside and around the buildings) and in closed spaces (an apartment for example). Mobile AR application was developed for the open space situation using georeferenced AR and the Junaio browser.

With the ease offered by devices with multiple functionalities associated (for example georeferencing and compass), as the iPad2 tablet (Apple, Inc.), an AR application was chosen considering the visualization of 3D models in real scale to be seen with this device. The application Junaio (Metaio Inc.) was used for the first tests. This application enables RA with or without use of markers, 3D object tracking and the ability to embed multimedia content. The 3D model imported by Junaio are OBJ or MD2. Object Files are text based files describing a geometry and its texture, it supports both polygonal and free-form geometry (curves and surfaces). The Md2 format is a binary format originally created to be used in a game (Quake-2). Its characteristics includes geometric data model (triangles), animations frame by frame and structured data model.

#### 4.1 3D Modeling

The BIM model was developed using AutoDesk REVIT. Terrains (natural and leveled) were modeled based on level curves and the buildings were modeled based on 2D plans and sections. Information was taken from construction drawings. However, the resulting BIM model was detailed to the level of LoD 300 (Figure 5).

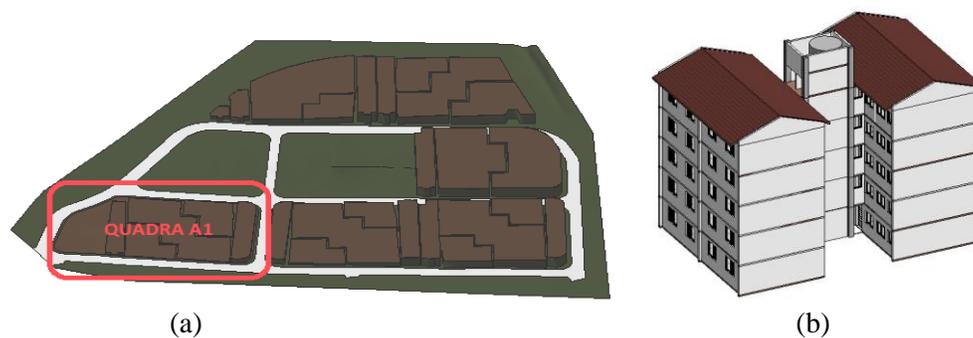


Figure 5: BIM Revit model (a) Campinas F natural terrain model and leveled plateaus and (b) two buildings interconnected by the circulation

#### 4.2 Model Treatment

One reason to treat the model was the need of visibility of overlapped objects (real x virtual), in order not to hide extra existing built environment elements when not present in the virtual model. The virtual model which should represents the initial site condition. Two applications were first tested for model treatment: 3D Max and Blender. The export and import process from REVIT to these applications resulted in loss of model information or presented difficult use, therefore were abandoned. Finally, Sketchup (Trimble) was used presenting satisfactory performance (Figure 6). The low or non interoperability between used applications (modeling and AR) is a drawback and indicates need of collaboration between software development company. This limitation was partially resolved.

The model used in AR by Junaio must be uploaded to a model server and communicated to the application by Internet during visualization. Therefore there is model size limitation of 750 Kbytes. This fact does not prevent the use of larger files, however, using larger files will likely result in problems such as slow transfer increases due to Internet bandwidth. This is another reasons why model treatment was necessary, to reduce model size. Figure 6a shows the buildings on terrain as in the real site and Figure 6b presents the simplified model, i.e., the terrain with less buildings to obtain a file size as required by Junaio, both with transparency and simplified in terms of elements. To visualize the 3D model without losing the reference or the real building, the material was modified to translucent material with an opacity about 80%. Furthermore, the model was simplified by eliminating component details from doors and windows for example and some buildings were removed of the terrain and the file got with about 600 Kbytes.

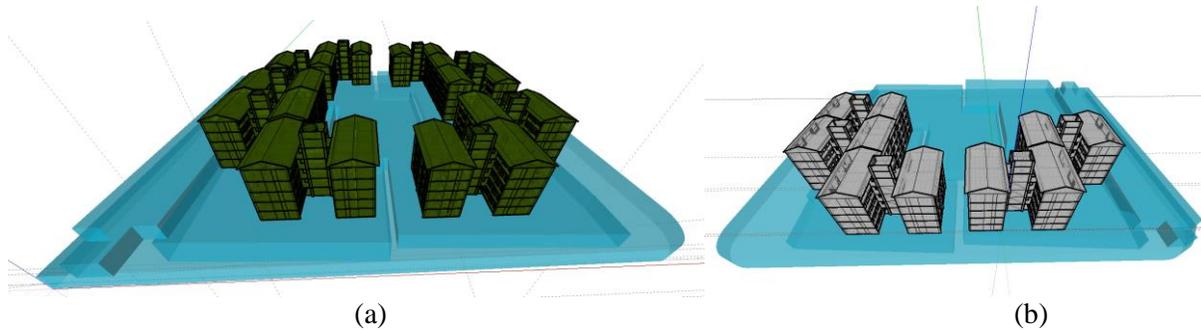


Figure 6: (a) One block leveled terrain with transparency (realized with Sketchup) and (b) reduced and simplified model to meet file size limitation imposed by Junaio

### 4.3 AR Application Development

Metaio is an Augmented Reality company that offers products and a variety of development features. Junaio is Metaio's mobile Augmented Reality platform that allows the creation of content channels for the real world. It offers three platform-specific programming interfaces: Android, iOS and Windows. The programming interface for Windows offers as alternatives: the developing environment (SDK) for Windows; the C++ language and the Augmented Reality Experience Language (AREL). Junaio mobile AR platform combines real world medium and virtual content. The accepted real world mediums are 2D object tracking and detection, 3D object tracking and detection, marker tracking and detection, SLAM tracking, instant tracking and GPS or inertial tracking. Possible virtual content are: games, 2D or 3D content. The AR experience can be delivered by native app or AREL/HTML5.

Once the virtual content is developed it must be associated to the real world medium and delivered for use through the Junaio browser. Metaio offers various developing alternatives by means of a robust architecture (Figure 7a) and delivery system (Figure 7b). Our study used a subset of this structure, that is: the Junaio mobile AR browser for iOS interface, the programming interface for Windows platform with AREL, the Eclipse environment for PHP Development Tool, WampServer for local content management, Metaio Cloud and Junaio API (Figure 7 marked in red). The world medium was GPS or inertial tracking and the virtual content was 3D built environment model (described in the previous section).

The 3D content, reduced to one block of the social housing was modeled in conditions (format, size and units - mm) for the Junaio mobile AR browser, then testing regarding mobile AR creation and delivery was initiated. The mobile AR creation was realized with the Eclipse environment: this includes configuring a scene to Junaio channel. The scene is configured associating a position in the 3D content (the coordinate system origin) to a specific georeference position on site (LLA - latitude, longitude and altitude). This scene is exported as a channel by uploading this content from local server (WampServer) to the delivery channel (Metaio cloud). The result of this deployment process is a free Metaio Cloud App Junaio. The Junaio Channel acts as a website or a TV channel simulating a distribution platform or a browser for the AR experience. This channel goes through a validation process when it is first created.

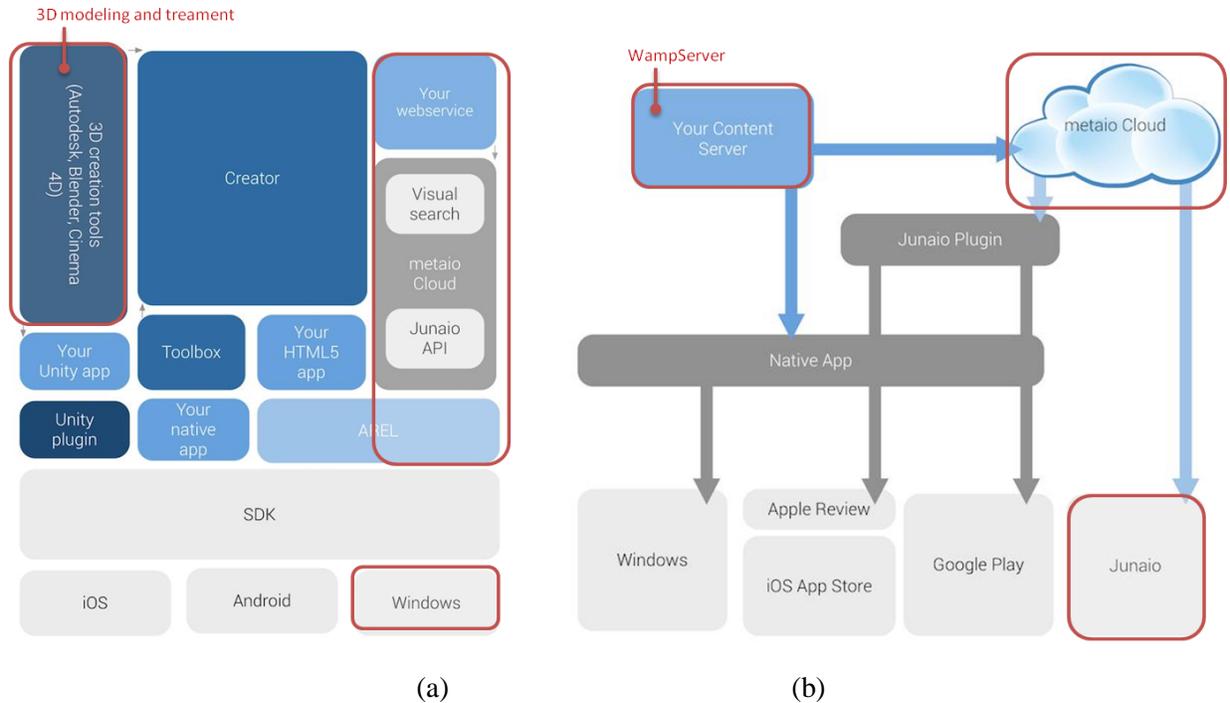


Figure 7: Used resources of Metaio: (a) architecture and (b) delivery

The created Junaio channel for the POE of the Campinas F was tested and resulted in the images presented in Figure 8 (b, c). This action is equivalent to initial tests of the experiment, still presenting unsatisfactory results. Two difficulties still remain: controlled process for model scaling and strategy for best choice of system coordinate origin definition depending on observer position on site (Figure 8).

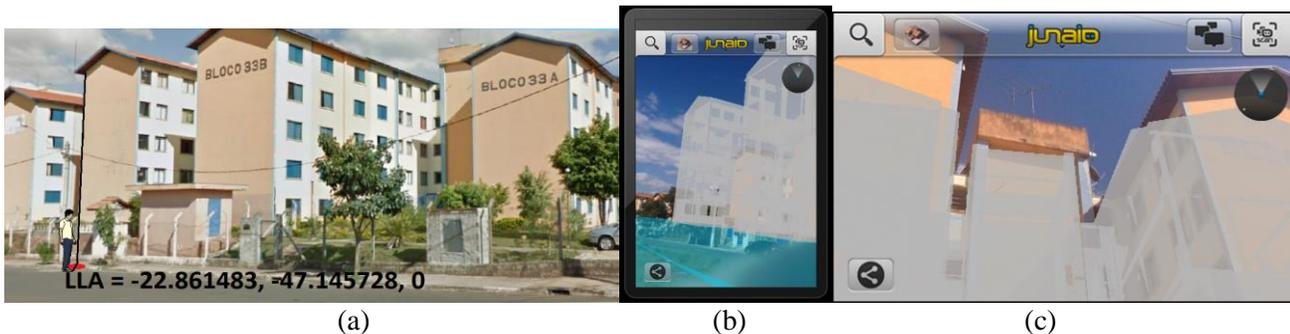


Figure 8: (a) Defined POI (with LLA) in the site; (b) and (c) First results of real scale AR model visualization

## 5. CONCLUSIONS

The development and application of AR in design situation, here represented by a POE study, using out of the shelf applications is still difficult and with shortcomings. The selected mobile AR development platform is complete and robust, but in constant evolution and requires medium to high knowledge of programming. It is necessary modeling knowledge as technical information on treatment and optimization for virtual models for effective use in these systems. There is also the issue of limited levels of use with restricted support, maintenance and installation associated to free use resources.

Questions of positioning and scaling of virtual objects in the real environment are important factors for mobile AR use in AEC. Behzadan & Kamat (2007) demonstrate how to understand the relationship between the distance from the user to the virtual element according to the data of latitude, longitude and altitude of both. This

information affects how the virtual element is seen by the user according to his current position. Calculation is complex, for every user movement in relation to a virtual object, recalculations are performed for that position to be maintained under the new point of view of the user. With mobile devices, these calculations and geolocation are made directly by the device via GPS and digital compass, requiring no user intervention. However, our tests indicate that it is possible that the available algorithms are limited, restricting movements to a specific situation as rotating around a point for example. This is inference from the difficulty in maintaining the 3D content static while walking in one direction, but not if rotating around a fixed point. There was also difficulty in adjusting the 3D content scale in order to obtain 1:1 scale to site visualization. The unit used in the modeling application (that is mm or m in ArchiCAD, REVIT or Sketchup) influenced this process. The choice of system coordinate origin in the 3D content (or BIM model) also influences visualization on site limiting/or disturbing scale adjustments (small movements may take 3D content out of site with difficult recovering).

Still with respect to out of the shelf technology available for mobile AR, the fact that the 3D content must be uploaded and rendered in real time through Internet, represents the need and dependence of good connection favoring the download time of information. However, in POE studies the 3D models are in large scale and need to be detailed for precise comparison. BIM models for facility management, representing building use situation, are of the highest level of detail (LoD 500). Therefore, it seems to be counter intuitive to simplify 3D content for upload and download performance issues. A balanced point between simplicity and representativeness should be found in this case. This was the solution adopted in this experiment. The LoD of the model itself did not change, for only information that did not interfere with the verification of exterior renovations was filtered from the model (as window glasses, internal equipments, and so on).

In terms of modeling precautions, it should be observed that the original BIM model must represent, at least, final state of construction (when it was delivered to the user). This was not the case of the BIM model used, the design drawings did not include detailed information of external stairs, ramps, trash disposal, ordinances and water inlet. Thus, it should be noted that the model to be used in POE with AR has to contain all these original details to allow a correct analysis by comparing the content viewed.

Low interoperability between modeling application and AR application (REVIT and Junaio) or between modeling applications was resolved by model flow between applications with interoperability through a sequence of export and import process. This transformation process, between applications, allow translation between model formats but may result in information loss, yet were acceptable, therefore not harming the test. However, this solution to low interoperability incorporates extra effort to the process.

## 6. ACKNOWLEDGMENTS

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