ARCh4models
A tool to augment physical scale models

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This paper focuses on the development and evaluation of a computer tool that enriches physical scale models of buildings, which are commonly used during architecture and civil engineering design processes. The main goal of this work is to enable designers, namely architects, to use the affordances of the physical scale models, by enhancing them with digital characteristics that can be easily changed, allowing an enriched interaction of the designer with such models. Our in-house developed Augmented Reality tool, referred to as ARCh4models, augments the user experience with visual features and interactive capabilities, not possible to accomplish with physical models (see this video in https://goo.gl/5zbdTQ). The tool allows the coherent registration between the real and the digital in the same space. Satisfaction evaluation studies were conducted that have shown that ARCh4models improves the building design process when compared with a traditional methodology employing solely physical scale models.

Keywords: augmented reality, architecture, physical scale model, 3D model, AEC design process

INTRODUCTION
Technologies are playing an important role in the recent history of our civilization and a large number of citizens use daily their computer, tablet or smartphone, for professional or personal tasks. Likewise, a large part of architects and architecture students use these tools in their daily professional or academic work. Simultaneously, architecture professionals and students use traditional means to express and explore their design ideas and concepts. Physical scale models are design tools still common because they allow a closer interaction with the designed buildings, increasing the understanding of the design.

Architects, engineers, designers, real estate promoters and other stakeholders that intervene in the building design process, adopt various methods to represent and visualize buildings. Two relevant scenarios are: i) the different design process phases, from conceptual to detailed design, when design alternatives have to be compared, and ii) when designs
are being presented to clients, future users or in design competitions. Drawings at different scales, rendered synthetic images, or three-dimensional physical models at several scales, are some of the used techniques. This diversity of methods doesn’t allow a clear comparison since they use different criteria for representing buildings. Whereas the traditional methods of visualizing architecture rely on drawings and on the construction of scaled physical models, the more recent approaches, rely on digital representations, either on 2D or 3D, using different commercially available Computer Aided Design software systems. Each method has its potentials and drawbacks, and only a minority of professionals or academics use purely one of them, whereas the majority usually goes back and forth between analog and digital, until the final design is reached, presented and constructed.

Our paper focuses on the representation of designs by means of physical scale models. Its affordances provide a good representation of the reality not reachable by a drawing and, given its three dimensionality, allow stakeholders to see them from different perspectives helping the perception of the constructed and void spaces.

According to Mills (2007) physical scale models can be categorized into two groups: primary and secondary. Primary models explore concepts and ideas and these are the ones more used for design purposes. Within this group Mills (2007) includes: conceptual models, volumetric models and presentation of models. In the group of the secondary ones, which are made with a greater detail, the author includes: inside, section facades and structure models.

Scale models help architects to understand a place. Volumetric models, in particular, show the city’s fabric by representing its volumes and topography, partially or fully. These urban models give designers three-dimensional information on how the area is developed, and with them architects can study the environment surrounding their place of study. Mills (2007) considers that urban context models are relevant, specially to show the adjacent territory surrounding the proposed design and are useful to visualize and analyze simultaneously several design alternatives for a design brief. Particularly in the initial phases of the design, answering to the design brief, several proposals for the intervention place are discussed and analyzed in the relation with the adjacent environment. Physical model buildings are still commonly used in architectural offices and will remain to be so. Those models are often short in information and focus mainly in volumes. They are static objects and cannot be easily and quickly changed. If more information would be made available, the architectural design goals could become more explicit.

As stated in Luciano (2012), both physical and virtual model help to visualize the three-dimensional shape. In fact, in recent years, Augmented Reality (AR) applications available in smartphones and tablets, emerged in the academia and in the industry. City Lens (1), for example, is an AR app that shows extra information about the street the user is seeing in real-time, like the location of nearby cafes, hotels, etc. Urbasee (2) is an AR app that allows to view a digital model in a 1:1 scale at given place. SmartReality (3) and Augment (4) enables the visualization of building products and other elements superimposed to a image marker.

This paper is structured in six sections. In this section we described related literature work that is in line with our research, notably about the use of representation tools in architecture design process and augmented reality in architecture. In section two we define the research hypothesis, the goals and the methodology used. Section three explains each step of the design of the Arch4models app, including the user interaction experience and its main functionalities. Section five presents the satisfaction evaluation studies. In section six we discuss our results and the paper end with a conclusion section.

HYPOTHESIS, GOALS AND METHODOLOGY

In our research the aim is to understand how we can bond together physical and virtual representa-
tion modes by superimposing (or registering) them, to increase the understanding of an architectural design, while at the same time showing the alternatives or the evolution of such design. Our hypothesis is that designers, architects and students would benefit with an augmented reality tool that help them to visualize their designs, to compare changes and to analyses their proposals within the urban context (Figure 1). Urban physical models are those that we believe can benefit the most from such a tool, since the rehearsal of alternative design proposals is frequently done at this scale of design work. At a different scale other functionalities can be of help as well to the design process as we will show in the next sections.

Given our hypothesis, our research work had the goal of allowing architects and other stakeholders to make a better use of physical scale models, providing them with more information than they have. To reach such goal, we developed and evaluated (with a satisfaction user study) an AR app to augment physical scale models. Our research methodology, included the study of the state-of-the-art of the available technologies that allow to add extra information to what we see in our world, as stated by Azuma (1997): “AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world”. Affordances and drawbacks of using physical models in the design process were also identified in order to propose solutions that took advantage of the potentials and surpass the drawbacks.

The methodology for the development of our AR app included six steps: i) definition of personas; ii) definition of scenarios used by personas; iii) definition of user requirements derived from scenarios, iv) development of the app that fulfils user requirements, v) satisfaction user evaluation study. The app was developed in a collaboration between architecture and computer science researchers from the Digital Living Spaces group of ISTAR-IUL and Microsoft.

ARCH4MODELS

**Definition of personas, scenarios and requirements**

In order to identify the requirements for the AR app, two scenarios and their corresponding personas, were defined: 1) a jury analyzing several proposals in a competition by different architects (Figure 2); 2) a team of architects assessing different alternatives during the overall design process. In the first scenario, the competition organizers would ask for participants to deliver their design proposals following a specific format of 3D modeling, to simplify its exchange with the Arch4models app. After importing those 3D models in the AR app, the jury could experience an augmented scale model in a Microsoft Windows tablet, where different design proposals could be superimposed into a same urban scale model. The second scenario assumed a similar scenario, but here the users would be more aware of all the presented proposals and would discuss smaller details. In both scenarios, the personas could have discussions about the proposed designs and its integration in the intervention places.

The final set of user requirements for the proposed AR system, were:

- Superimpose (register) in 3D and in real-time, the virtual model with the physical scale model;
- Perform augmented reality by means of texture (image) tracking, using in-house developed technique by Bastos & Dias (2008);
- Import several 3D models described in the standard 3DS format in one augmented reality session;

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**Figure 1**
Student’s urban context physical model, with a hole in the intervention plot so that the proposed building can be placed and continuously replaced. (photo by Joana Gomes)
• Show and hide building components (architecture, structure, infrastructure);
• Perform real-time sections and floor plans.

Arch4models development
The ARch4models app is an extension of a previously available the ARch app (Lopes et al. 2014; Mendonça 2014; Miguel 2014), which was designed for a Microsoft Windows tablet (Figure 3). The interface was designed to be natural and simple so that the user can quickly and easily navigate through the menus. There is a menu that occupies 25% of the screen when a 3D model is open and the goal is just to explore the model in AR, leaving the rest of the screen free of graphical gadgets. Some features included in ARch4models were already available in the ARch app, which was previously designed to be used by architects during the design process, without any use of physical scale models.

Augmented Reality technique
ARch4models uses a texture-based augmented reality system (Bastos and Dias 2008) to recognize and track in real-time features of a reference image, with known position and orientation in relation to the actual physical scale model. Thus, the tracking information is used to register in 3D the virtual model and the digital data corresponding to a building. Through the screen of the tablet, the virtual model appears superimposed at a location near the scale model, much like if it coexisted with such physical model (Figure 3), resulting in an augmented physical model. The procedure requires the following: a Windows tablet; a virtual 3D model; an image used as a marker; a physical scale model.

Recent developments of our recognition technique allow us to already identify the physical scale model as a marker as stated in the Discussion section.

Arch4models features
Change between 3D virtual models. A menu enables the user to change the 3D model. This means that several 3D models can be loaded into the system simultaneously and seen whenever the user wants. When there is the need to change a 3D model, the user has to slide with the finger from the menu bar to open the “change menu”, and in this menu the user needs to do a long click on the selected model. Then the user can close the change menu, sliding to the left direction in the same bar (Figure 4).

Cut sections. In the sections mode, the user can make horizontal or vertical cut sections to immediately observe the inside of the building designed (Figure 5). These real-time sections can be performed in any direction or angle.

Show architecture, structure and infrastructures. In selection mode it is possible to highlight, paint or hide the various specialties of the 3D building digital model (architecture, structure and infrastructure).
For this purpose, the model is divided by layers (design specialties) and the app is able to show them one by one. We can e.g. see the structure layer highlighted in red (Figure 6).

ARch4models contains other useful features for improving design discussion. With the Highlight tool, the user can point to an element, highlight it and discuss it with another stakeholder. The highlight and paint tool can also be used to rehearse design alternatives with colors or materials e.g. The Hide tool, allows the user to hide a wall of any other element e.g. to see the inside of the building without slicing it.

Digital model preparation
The ARch4models supports 3D models produced in any 3D modeling software, provided that they support 3DS export format. We require the building elements to be divided into specialization layers. Our app reads 3DS into a native OSG - OpenSceneGraph format.

SATISFACTION EVALUATION STUDY
Usability and satisfaction evaluation studies were performed which involved 16 adult participants from ISCTE-IUL, students of architecture and architects. These participants were aged between 19 and 50 years old, 12 men and 4 women. All participants were experience users of physical scale models - 44% of participants said that they create models many times, 38% with reasonable frequency and only 19% rarely. The study included, for each participant, the following 4 phases:

1. A five minute demonstration of ARch4models performed by the authors;
2. A five minute free exploratory experience of the app by each participant;
3. Three prescribed tasks performed by each participant: i) change model; ii) perform a section or floor plan; iii) show structure or infrastructure;
4. Satisfaction questionnaires.

One of our goals was to assess the relevance of using ARch4models during the communication between various participants in the design process, like in reviews of architecture juries. For that we defined several questions that participants answered by using a scale of responses from 1 (not good) to 7 (very good). 94% of participants stated that the app makes it easier to understand the design in an urban contexts (Figure 7, responses 5, 6 and 7). 44% of participants said the application allows a very good (response 7)
and more dynamic view of the model while 94% responded with values 5, 6 and 7 to the same question. With the help of the AR tool, 82% of participants said they would be interested in using it in their design processes. These results show that ARch4models can be useful to the architects’ work. The app also had a positive vote on its usefulness for the evaluation of several design alternatives for the same place, as in a competition. In fact, 88% of participants agreed that the app would be an asset for the jury committee of architectural competitions, as enables juries to fully observe the design alternatives. Both students and architects involved in the test ranked 81% the possibility of adding more information to the models.

Participants were also asked what was their perceived satisfaction, namely, if physical scale models could become more informative when augmented with extra information added by AR. 38% said that 3D modeling satisfy them in a good way, 44% replied with a reasonable satisfaction while 19% said they were insufficient compared with the others. About technology, only 38% responded that they had prior knowledge about AR software.

DISCUSSION
The results obtained with the ARch4models app enable us to discuss on the role of such an app during the design process as a whole.

Physical scale models are used to explore concepts and ideas during the design process and assume several detailing levels, some only volumetric, others more detailed and even others fully detailed namely showing construction components. Arch4models aims at several design stages since it incorporates features that help architects and other stakeholders along the design process. At an initial design stage, when architects are discussing urban design and volumetric possibilities, Arch4models enables the visualization of several design alternatives superimposed to an urban physical model. One advantage of such a tool in this stage is the possibility of having several design alternatives that can be interactively visualized superimposed in the physical model. In later stages of design, when solutions are more detailed, Arch4models allow to explore the interior of buildings by using features as Sections and Highlight. At this stage Arch4models enables to explore the proposals in several scales of detailing ranging from the urban position to the construction detail.

Figure 5
The user performing real-time horizontal sections in the 3D model.

Figure 6
Highlighting the structure of the 3D model.

Figure 7
Responses for: does the app makes it easier the understanding of the design in an urban contexts (values form 1 to 7, 1 being no)
As a result of our user studies, both from qualitative assessment of participants and features that we defined and were not implemented, we have realized that there are some aspects of ARch4models that we need to improve or extend: i) in Presentation mode, introduce the simulation and animation of insolation; ii) in Section mode the vertical cut plan needs to be improved so that users can define the rotation angle; iii) both Highlight and Paint tools should enable to save the generated data.

As we stated before, our currently operational AR system is based in texture tracking, requiring a reference image to be in view of the camera, to correctly register the virtual model. Although it wasn’t reported as a problem during the usability studies, this assumption limits the volume of interaction allowed, especially if we consider larger scale models or camera’s close-ups. A possible solution would be the adoption of several reference images placed around the physical scale model. However, we decided to integrate an AR tracking solution that completely removes the need of images. We have experimented the use of Microsoft Kinect camera (5) and an available 3D reconstruction and tracking technology from Microsoft (Kinect Fusion (Newcombe et al. 2011)), to simultaneously reconstruct and track the geometry of the physical scale model and remove the need of reference images after an initialization step. At the moment, this experiment runs only on laptops with graphics processing unit (GPU) computing capabilities.

Using this version, the initialization step occurs in the first frames camera frame: Arch4models recognizes a reference image, performs Camera Pose Initialization (CPI) and calculates the transformation from camera to world coordinate systems. Afterwards, the reference image can be ignored and Kinect Fusion reconstructs and tracks the physical model maintaining both virtual and real visually consistent. Using these technologies is possible to walk around the physical model without losing the position and orientation registration of the virtual model in AR. The system requirements are the following: a computer with a GPU computing capabilities; Kinect for Windows (first version); a virtual 3D model; a reference image just for CPI; and a physical scale model.

To assess the accuracy of this setup, tests were performed with several scales of physical models and building materials (see Figures 8 and 9). We were able to perform CPI and track the camera pose in all scale models, although the frame rates were very low (around 5 fps) and the instantaneous pose still shows excessive accumulated errors. In Figures 8 and 9, we can see that with this technique we cannot reconstruct scale models smaller than 1:1000, because the volumes are extremely small. Also trees and smaller

**CONCLUSION**

Arch4models app includes a combination of features that makes it very adapted to the architectural design process. Most AR commercial apps have single features that enable to visualize architecture models but fail in providing the flexibility required by a professional use, namely the possibility of doing real time sections and visualizing it by layers while simultaneously the 3D model is superimposed on the physical model.

This paper focused on the use of Augmented Reality to improve the experience designers have with
physical scale models. We hypothesized that augmenting the information present in a physical scale model, would improve the use of those models during the design process. The goal was to develop and evaluate an AR app able to augment scale models with dynamic design information, enabling architects and other stakeholders to interact with them in an easier and more effective way. We concluded that our approach promoted dynamism and simulation possibilities to the real scale models, previously unavailable. The developed app allows to select and perform sections on the virtual model in real time, which is registered onto a physical scale model. As a result of this work, the scale models become more dynamic and interactive. The user can test several design alternatives applied e.g. to an urban context, and easily perceive aspects to change or improve. Satisfaction tests showed that this application has the potential to be used both during the architect’s working process and during the evaluation of designs competition.

We believe that our tool has the necessary features to help the stakeholders involved in design processes of buildings and urban areas.

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REFERENCES


Miguel, R 2014, Realidade Aumentada Aplicada ao Processo de Projeto de Arquitetura, Master’s Thesis, Instituto Universitário de Lisboa (ISCTE-IUL)

Mills, CB 2007, Projetando com Maquetes, Bookman
