Barbara E. A. Piga [a], Valentina Petri [a]
[a] Laboratorio di Simulazione Urbana 'Fausto Curti' (labsimurb), Department of Architecture and Urban Studies (DAStU), Polytechnic of Milan, Milan, Italy

Augmented Maquette for Urban Design

Introduction

Augmented Reality (AR) is used in different disciplines with several purposes. In the field of architecture and urban planning it can be very effective if applied to anticipate design projects and their effects. This can be done on-site, through the augmentation of the transformation area, or off-site, using physical models of the same context. This contribution focuses on Augmented Reality[1] with physical scale models, later named *Augmented Maquette*.

AR enable to join the specific characteristics of the real and the digital environment, and in so doing the user can take advantage of the peculiar and unique nature of both. This is the reason why we believe that the application of such a tool can be very effective in supporting an informed dialog between the different actors involved in the process of urban transformation, including stakeholders, decision makers and citizens. Likewise, it can be very effective for higher education in architecture and urban studies.

The paper presents pros and cons of physical and digital models and advantages and disadvantages of a mixed solution. It briefly describes a qualitative comparative study among three selected apps for AR, based on the evaluation of their efficacy in outdoor environments and with scaled models. It then outlines the typology of "layers" that can be added to physical models for generating experiential dynamic *maquettes*.

Physical and Virtual models

The way we represent our design projects has of course an influence on design thinking, and hence on the design process and the final outcomes[2], as it is clearly shown by several architectural projects around the world. The use of physical mokups as a tool for supporting design thinking, evaluation and communication of design proposals is not new to the architectural domain. The use of digital models, instead, is relatively novel even if it is already widely

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[1] Some references to the research on the topic of AR for Urban Design done at *Laboratorio di Simulazione Urbana 'Fausto Curti'* of *Polytechnic of Milan* are: Piga, 2010; Cibien et al., 2011; Piga et al., 2015; Piga & Morello, 2015; Calabrese & Baresi, 2017; Cibien, 2017.

[2] Sarkar & Chakrabarti, 2008

adopted around the world[3]. In parallel to the technological advancements, the recent innovative modeling procedures are widening the possibilities of making mockups in both approaches; in fact, along with the traditional ways of modeling, the introduction of Computer Numerical Control (CNC) machines in the field of architecture led to new ways for manufacturing physical mockups based on additive, subtracting or cutting processes[4]; similarly, in the digital representation domain the introduction of procedural modeling opened up new possibilities.

The used of mixed solutions that combines physical and digital elements, that is Mixed Reality (MR) (Fig. 1)[5], that includes Augmented Reality as a subclass, is even newer, although in expansion. Anyhow, the era of a largely adopted Mixed Reality approach in the today professional practice or in higher architectural education is still at the very beginning. Since this process has just started and it is not largely diffused yet, the understanding of the implications on design thinking in the professional practice at a large scale can be only assumed.

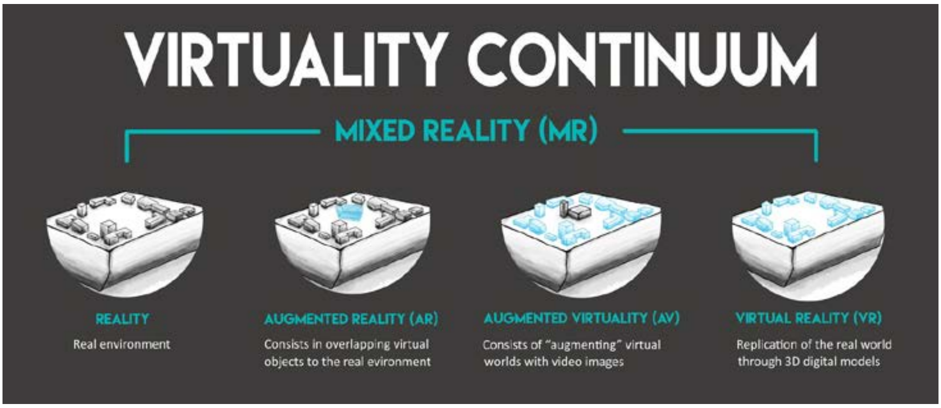

Fig. 1 Representation of the concept of *Virtuality Continuum* by P.Milgram, T. Haruo, U.Akira, F.Kishino, 1994[5]. (Image credits: Valentina Petri)

Moreover, even when applied, these types of solutions are generally confined at the end of the process, namely to the phase of communication to clients and other stakeholders. Despite this, it is easy to suppose that the opportunities provided by this mixed approach will be soon wider, impacting the design process from conception to final construction.

The combination of physical and digital models will enable to take advantages of the specific characteristics of both media, enabling at the same

[3] Mitchell & McCullough, 1995
[4] Capati, 2017
[5] Azuma, 1997; Milgram et al., 1994; Van Krevelen & Poelman, 2010; Barba & MacIntyre, 2011; Calabrese & Baresi, 2017

time to partially overcome the limits of both; for instance, it would be easier to simulate different weather condition on a physical model. Anyhow, as shown below, an analysis on Augmented Reality apps on the market shows that there is still a lack of products dedicated to the augmentation of physical models, even if there are researches working on the subject[6].

Physical models have been always widely used for assisting the design development and as a – easy to interpret – communication media for presenting the project to clients and other stakeholders. The main relevant property of scaled models is that they are physical. Their tangibility reduces the gap between representation and reality and this generally ensures the easiness of understanding of contents, especially for lay people. Moreover, with its solid three-dimensionality, mockups are generally perceived as trustable. This perception is reinforced by the fact that their scale cannot be modified, unless to build another mokup; in other words, it is not possible to zoom in and out physical models and it is possible to visually measure and compare the represented urban elements among them, without panning the model on the screen.

The scale has of course a direct impact on the level of details that it is possible to achieve. Coupled with the portion of space it represents, this define the dimension of the final model, that is often difficult to transport or to send. Of course the variable of the scale and the area to represent are inversely related, hence, in order to produce a territorial representation of an area we have to increase the scale, unless we have a wide place where to locate the model. But over a certain degree of its dimension the problem of usability would occur, since the inner part of the model would be less accessible – either visually or for manipulation – then the peripheral area.

Another important element of physical mockups is that they generally depict a moment in time, even if it is possible to use analog tools to simulate different circumstances on a model, e.g. wind or lighting conditions[7]. If materials are used consciously their materiality can of course effectively replace the characteristics of the physical world, and so these can be effective in giving back reliable physical reactions in different ways, from the building structure and the process of construction[8] to sound reverberation and so on.

On the contrary, the main important feature of **digital models** is that they are not physical. This is an obvious consideration that implies a lot of consequences and that make physical and digital models hardly interchangeable. Renders are increasingly adopted for the communication of design projects to

[6] Cibien, 2017
[7] Podestà, 2017
[8] Rossetto, 2017

lay public, but the trustfulness of their representation can be perceived lower than physical models; in fact, it is harder to visually weight the tridimensionality of the area, as we do with scaled models, and to individuate inaccuracies.

Differently from physical mockups, digital ones do not allow a direct interaction, that is in fact mediated by an interface. Of course interfaces that allow an immersive and naturalistic interaction[9] are easier to use, especially for lay people. In fact, the use of 'go between' devices, such as mouse and keyboard, can result annoying for people that are not used to deal with these kind of tools in everyday life. Anyhow, tablets and smartphones are becoming more and more integrated in people's activities at any age, and this is gradually thinning the digital divide, that in any case is destined to disappear.

While scaled models cannot be resized, digital models can be zoom in and out allowing the observer to rapidly pass from one scale to another. Even if in doing this it is of course easy to lose the sense of scale of the area, this allow a flexibility in linking details and larger views that is impossible with physical mockups. Hence, the level of details that is possible to embedded in a digital model has potentially no limits, and the same for the portion of territory to represent. The limits are in case given by the weight of the final product, the performance of the machine and of course the time and ability needed to perform the process. This intangibility of digital models allows an easy exchange and transportation.

Moreover, the intangibility of digital models allows to easily act on time, for instance by passing from a period of a year to another one, or by compressing long periods of time in a short one. From the multisensory perspective digital simulations allow to calculate different types of data related to the future environment, but form an experiential perspective nowadays these can easily and accurately reproduce the visual sphere only; for instance, even if it is easy to embed the urban soundscape into the model, it is hard to realistically anticipate the final results of non-existing condition (i.e. the design project), especially for open areas, since the soundscape originates from the cumulative interaction of different elements. In fact, the procedure for simulating this issue is still not widely adopted, since the computation requires a relevant amount of information, a specific model that include for instance urban materials, software able to run the simulation and machines capable of running the analysis. Other senses are even harder to being correctly simulated, even if researches in robotics and human computer interaction are expanding the possibilities of using such data, thanks for instance to haptic interfaces and similar.

As shown before, virtual and digital models have different and peculiar properties. The combination of the two modalities allow to melt together the

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[9] Loomis et al., 1999

potentialities of both in a mixed solution[10]. **Mixed Reality** can serve two main applications in architecture: (i) *on-site augmentation* (ii) *in-vitro augmentation*. For instance, it is possible to simulate and test design project in 1:1 scale on-site, hence with a subjective view, or it is likewise possible to augment physical models with digital layers. Two main typology of digital informative layers (data) can be add in both cases: (i) *experiential* (ii) *dataset*. In the first case, it is possible to outfit the model with data that contributes to render the situation as it would be perceived in reality, e.g. shadows, people, textures and so on; in the second case the augmentation can show information related to the urban context, such as temperature or other weather variable, information regarding the number of people living the area, and similar. While in the first case we are in the range of *experiential simulation*, in the second one we enter the domain of *conceptual simulation*[11].

The combination of real and virtual elements can of course work with *indoor* and *outdoor* Augmented Reality, but also for *Augmented Marquette*. In this case, the information can be shown dynamically by a projection on the surfaces of models, as for the *Luminous Planning Table* - designed at Massachusetts Institute of Technology in the late nineties[10] - and similar tools[12], or through devices, such as tablet or Head Mounted Displays [Fig. 2]. While in the first case the direct interaction with the model is preserved, in the second one the interaction is mediated. In fact, with tablets or similar tools the interaction is intermediated by the device that remains always perceivable, i.e. the augmented view is confined within the screen of a non-immersive device and the direct interaction with the model is lost; in the second case, the interaction with the model is direct and naturalistic[13] and the device is no longer perceived. Of course, the first set of solution guarantee an easiness of use and an interaction that is more fluid than the second one. In both cases, beyond the quality of the model, the experience depends also on the hardware (immersive or non-immersive), and on the software used.

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[10] Ben-Joseph et al., 2001
[11] McKechnie, 1977
[12] Cibien et al., 2011; Cibien, 2017
[13] Loomis et al 1999

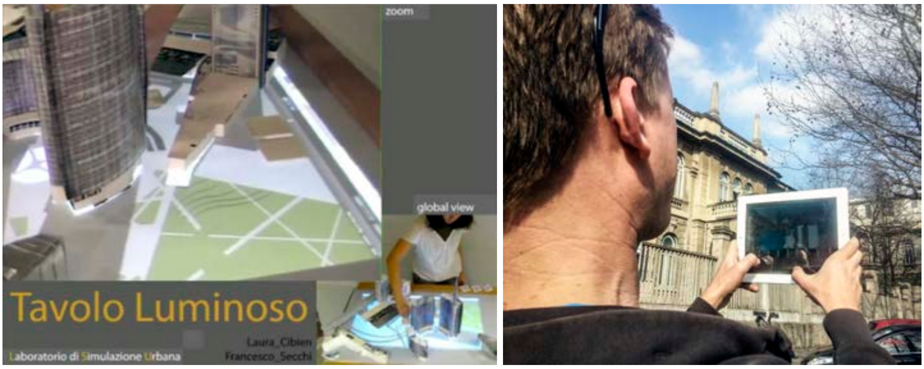

Fig. 2 (a) Tavolo Lumiso (labsimurb – POLIMI 2010). By rotating a physical button it is possible to modify the shadow casting on the interactive table surface
(b) Onsite AR testing for the “Ri-pensiamo via Celoria” project by labsimurb for the *Città Studi Campus Sostenibile* inter-university project (2014)

As recalled before, to the authors’ knowledge, **Augmented Reality** solutions today on the market are not designed specifically for augmenting physical models, named here **Augmented Maquette**. It is then necessary to use applications designed for indoor or outdoor AR and – improperly – apply them to physical models. This imply a set of problematics related to the correct geo-location of the virtual elements within the scaled mockup, to the fluidity and stability of the visualization, and so on. In order to understand which is (today) the most suitable app for augmenting physical models, an investigation of (Android) apps was done by the authors. From a wider list of AR app for architecture, we selected the three that seemed to be the most suitable for our purposes, namely: SightSpace by Limitless Computing Inc., Augment, and Urbasee by Artefacto. A qualitative analysis of the apps has been performed comparing their performances in outdoor environment with the ones with a physical scaled model of the same area; the analysis was developed investigating the following technical issues: (i) Stability, (ii) Responsiveness, (iii) Texturing, (iv) HMD – Head Mounted Displey (v) Markeless option. More in detail:

- *Stability*: level of steadiness and alignment of the 3D model to its location in the real world. In particular, the digital model should remain stable and with a low rate of flickering at its location and correctly collimate to the real context even when the user is moving around. This is related to the Tracking System Delay that is the “time [needed] to measure the position and orientation of the user’s head” together with the Image Generation Delay, that is the “time for the graphics engine to generate the resulting picture”[14].

[14] Mine, 1993

- *Responsiveness*: the degree of real time reaction of the virtual environment when a rotation/move/zoom command is input. This is linked to the Image Generation Delay.
- *Texturing*: the render quality of the texture of the model.
- *HMD*: when the app allows to visualize the model with a simple Head Mounted Display this issue assesses the responsiveness of the app to the navigation with such a device. This is important because in case of slow synchronization - namely latency - between the movement of the user and the relative movement of the scene, this delay often provokes nausea and discomfort. This is linked to the Display System Delay, that is “the time required to display the image in the Head Mounted Display[14].
- *Markerless*: this issue simply says if the app can work without a Fiducial Marker as a reference for correctly locating the model in the real context. Apps that do not need this reference are classified as markerless; these generally locate the model according to the geo-spatial localization of the user for on-site navigation, or thanks to beacons, or 3D scanning\tracking and recognition of the environment and its elements (i.e. computer vision: image recognition and 3D object tracking).

An assessment of the apps performances for each issues between (i) and (iv) was done and a qualitative evaluation, ranging between low, medium, high, was associated to each app. It is important to highlight that the 3D model was modified, e.g. simplified, in order to work properly with such tools. The outcomes of comparative assessment are synthetized in Fig. 3.

1 - LOW 2 - MEDIUM 3 - HIGH	Stability	Responsiveness	Texturing	HMD	Markerless
SIGHTSPACE					
OUTDOOR	2	1	2	VR only	✓
MAQUETTE	1	1	2	VR only	
AUGMENT					
OUTDOOR	3	3	2	-	✓
MAQUETTE	2	3	2	-	
URBASEE					
OUTDOOR	2	2	3	-	✗
MAQUETTE	1	1	3	-	

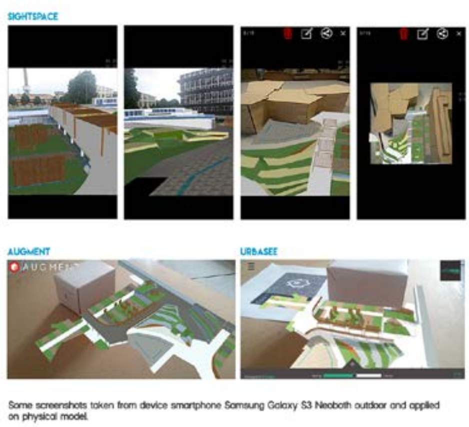

Fig. 3 The matrix shows the results of a comparative analysis between the three mobile AR applications under investigation: SightSpace, Augment, Urbasee. The right side of the image presents the qualitative results of the study: for each app a comparison between outdoor and indoor performances was conducted according to stability, responsiveness, texturing, Head Mounted Display, markerless option. If read together the matrix allows a comparison between the three applications. On the left side of the image it is possible to visualize some screenshot of the testing phase: the first to images (up-left) refer to outdoor AR, while all the other to in-vitro AM

The three apps, as expected, behave better in real environment than with scaled models. In fact, the reduction of the 3D model to the scale of the physical mockup generally generates some problems in the correct functioning of the apps, even if by modifying and simplifying the 3D model the problematics can be partially overcome. For instance, SightSpace by Limitless works well for outdoor AR, but it loses stability when it works with scaled 3D models. SightSpace is the only solution, among the studied ones, that allows to use HMDs, but with Virtual Reality mode only. This is a relevant lack for AM solutions, since it is of course crucial for a two hands interaction with the physical models. Both SightSpace and Augment provide markerless solution that allow to resize, rotate and move the model on the screen. Stability and Responsiveness in Augment remain excellent in outdoor and on *maquettes*; the stability remains quite good even when moving the device. In a recent app implementation, the quality of texturing increased a lot, even if this is still not optimal. The quality of texturing is instead excellent in Urbasee, that assures the more realistic outcome among the three. Unfortunately, today, using Urbasee for augmenting scaled models is still not efficient, due to the low stability of the digital model and the low responsiveness, in fact the app does not follows the movement of the device in a congruent and fluid way.

Between the three apps Augment is the one that better fits the requirements for AM, but in general, stability and responsiveness are too low in all the app tested, while the quality of texturing can lead to medium\high results. Unfortunately, this parameter alone is not enough for a correct usage of AM for urban design purposes. In conclusion, the comparative analysis of the apps, shows that the development of the software for Augmented Maquette still need some relevant development for a proper application in the architectural field. It is in any case important to notice that along the research process we tested the apps several times, and in any new release the improvements done for AR were useful for AM as well.

Conclusions

Mixed Reality for urban design is still far from being efficient and within reach in the urban design domain. Too many technological constrains are still limiting its applicability at the large scale and within all the different phases of design projects. In fact, for instance, it necessary to clean and simplify the model for enabling mobile tools to correctly handle them, and too often the app should be set to correct visualize and geo-locate the mockup in the real environment; moreover, this setting process should be often repeated several times for reaching the proper alignment of the model. Hence, this solution is far from being fluid enough for being integrated in the flow of the design process. The problem of low performances of smart devices in handling big 3D models can be overcome by solutions that connect the device directly to Personal Computers that do the computation, but this solution reduces the usability of the system in terms of portability and, due to costs, of the number of devices that can be used at the same time.

Despite the technical problems encountered, we started a process for testing the applications of AR in architectural higher education within the course of Architectural and Urban Simulation, proff. B. Piga and R. Salerno, at Polytechnic of Milan, and within a process of public participation related to the Campus Sostenibile inter-university project[15]. These first applications allow to half-seen the benefits of such an approach, in fact they showed the potential usefulness of the tool, while highlighting the current technological constrains, that probably slow down the diffused use of such tools for urban design purposes.

A further technological development of tools and devices, let us envision applications that will allow students and professionals to use multisensory simulations of their design projects. Today, instead, when used for depicting future environments, these applications are mainly devoted to convey visual and kinesthetic aspects. If experiential simulations will be more integrated in the entire design process this will – hopefully – have a positive influence on design outcomes from an experiential perspective. It is in fact probable that its application will reinforce the attention on the human-environment interaction[16], rather than the architectural object per se.

The continuous rapid development of these applications allows to hope that there will be an improvement that would also involve the app usability with physical models. This will lead to a new generation of model making, that will consider a combination of digital and physical elements, echoing what is already happening in smart cities. Will Augmented Maquette be a novel and useful support for designing and envisioning the city of the future?

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[15] Piga et al., 2014

[16] Piga & Morello, 2015

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