Bridging the Analog-Digital Divide: Enhancing Urban Models with Augmented Reality

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Abstract: Physical models are a widespread tool for landscape intervention communication, however, their fixed nature limits their utility as both a discursive and a design tool. Using mobile devices, Augmented Reality can overlay 3D digital data into the world. In this paper, we demonstrate how Augmented Reality can be used to enrich 3D printed urban models to show competing designs, replace outdated physical designs, and contextualize urban models within a larger urban context. Using a digital twin and accurate physical occlusion, we show how Augmented Reality can be used in workshop settings to enable interactive demonstrations, encourage design exploration, and turn physical urban models into evolving comparative design tools.

Keywords: Augmented reality, visualization, urban models, stakeholder participation

1 Introduction

Along with maps and drawings, physical models are a core tool in the landscape architecture toolbox as a visual thinking and communication tool. However, the significant upfront cost and time expended in creating these models are at odds with the static nature of large-scale urban models, limiting their utility in the continually evolving urban design process. Ideally, a physical model should serve as a situated base design with which to embed progressive design changes, visualize and compare competing plans, and analyse possible future interventions using the physical context of the larger urban development plan.

Recent developments in augmented reality allow practitioners to augment physical models with digital data (PIGA & PETRI 2017). To support collaboration and stakeholder participation throughout the design process, a growing body of work has sought to use digital augmentation to expand the utility of physical models. Model augmentation increases the utility and flexibility of a model, opening up new avenues for design, evaluation and communication (ISHII et al. 2002, WALZ et al. 2008). There are several approaches to augmented reality (AR) currently used in landscape architecture. The most well-established method uses projected augmentations, combining a physical model with spatially calibrated data projected down onto the model from an overhead projector (BUCHROITHNER 2019, STELLINGWERFF & KUHK 2004, NIJHUIS & STELLINGWERFF 2011).

Mobile Augmented Reality has been used to enable explorable 3D models situated in the real world, using a mobile device (SORIA & ROTH 2018). It can be used to overlay a dynamic 3D digital model over the physical world, and has been used to demonstrate future interventions, and provide additional interaction data unavailable to physical models (LANGE 2011, TOMKINS & LANGE 2019).

However, embedding digital designs into a physical model is a complicated process. Due to a lack of fine-grained depth information, both mobile AR and projected augmentations suffer from the problem of physical occlusion (WLOKA & ANDERSON 1995, KRUIJFF et al. 2010),

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where a physical object cannot appear in front of, and thus occlude a digital object. This leads to certain restrictions on the use-cases of model augmentations.

Projected augmentations can only display 2D surface data, making it unsuitable for fine-grained information on and around complex designs. As such, it is a tool more suited to cartographic visualizations as opposed to design visualizations. Alternatively, mobile AR enables 3D models to be visualized as part of the real world. While it has been successfully used in scenario visualization, flood risk communication and collaborative design (GOUDARZNIA et al. 2017, HAYNES, et al. 2018, TOMKINS & LANGE, 2019). The current implementations of mobile AR are unable to interactively augment a detailed physical model with elements from a digital model without detailed user recreations of the occluding model geometry unsuitable for complex models (HAYNES et al. 2018).

This research introduces a novel Augmented Reality system to convert static physical models into dynamic discursive environments to expand the utility of physical models as a tool for education, research and stakeholder involvement. We demonstrate the transformative capability of an augmented physical model in representing the evolving urban design process, from preliminary city planning to detailed green-infrastructure design with a case study in the ongoing urban development process in Pazhou Island in Guangzhou, China.

2 Methods

To allow physical models to react to the evolving urban and landscape design process, an augmentation must be able to interact directly with the physical model. Ideally, when faced with a large scale physical urban model, discrete design changes such as the provision of new building plans, the design of green infrastructure, sub-surface features, land use designations, or inserting whole city blocks could be visualized in-situ as the need arises, without having to create new models.

In this paper, we detail the process of creating physically occluded augmented reality visualizations to enhance currently employed physical models, opening up new possibilities in dynamic augmented reality landscape architecture and urban design visualization. This will enable practitioners to augment a model with base-data such as land use and infrastructure, as well as document and communicate the evolution of the design process, and to enable situating small-scale design changes within a broader urban context.

In a situation where we have an equivalent digital twin of a physical model, we can tightly integrate dynamic augmented reality visualizations into complex physical models, through a new dynamic digital occlusion modelling process. Figure 1 shows the pipeline for creating the AR visualizations. We use a combination of 3D model recognition and tracking, a digital twin model, and custom shader programming with a modified render pipeline to enable physically occluded augmented reality visualizations of urban planning models, within the Unity Game Engine.

We developed within the Unity Game Engine, as it has a strong presence in the planning and design literature, with applications in public participation (GOUDARZNIA et al. 2017), spatial cognition (SORIA & ROTH. 2018) and future scenario visualization (HAYNES et al. 2018, TOMKINS & LANGE 2019). Using the Unity game engine enabled the integration of previously developed packages for participation studies (TOMKINS et al. 2019) while including the cross-platform Vuforia package to enable support for 3D model targets.

To reduce the barriers to AR adoption, our current solution requires no headset nor upfront software costs. We use mobile tablet-based AR to ensure a cost-effective multi-user set up, however, the technology is being developed with the capability to support headset based AR as required. Our digital model is designed in Sketchup, which provides the basis for both our physical model and digital urban designs used for augmentation. We present results using 3D Printed structures, produced on an Ender3 printer.

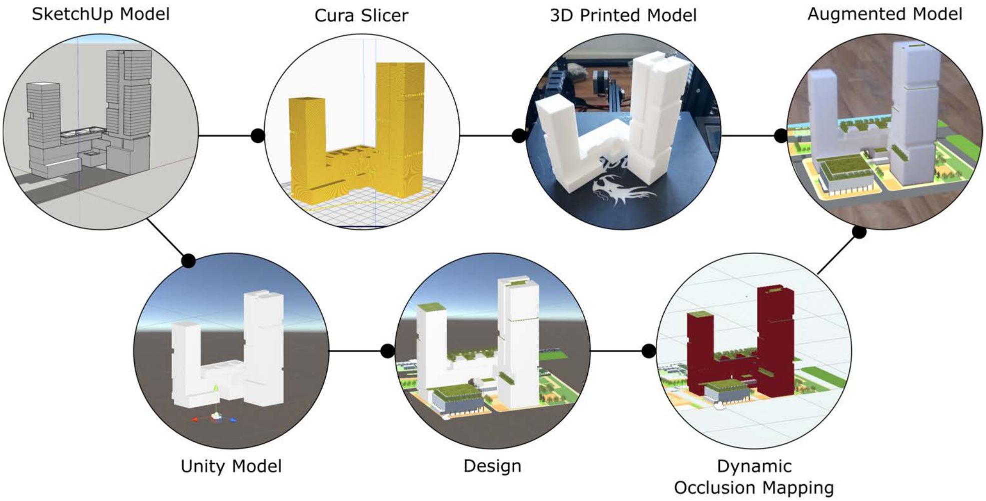

Fig. 1: Pipeline for the occlusion modelling process

Occlusion is achieved through custom shaders and materials applied to a spatially calibrated digital twin of the physical model in Unity, as shown in Figure 1. The occlusion mapping material applied to the digital twin is rendered earlier in the Render Queue to prime the Depth Buffer, whilst enforcing LEqual ZTesting in the shader. This results in only unobstructed geometry and geometry in front of the physical model being rendered, culling any hidden digital geometry behind the digital twin. The digital twin itself is not rendered and is only used as a render mask. This enables a physical object to be seen through the 3 dimensional 'digital hole' left in the AR overlay by the depth buffer culling of the digital twin. Importantly, physical buildings which would appear in front of our digital visualizations, appear to occlude our digital overlay, giving the impression of a genuinely situated digital design akin to the traditional glass painted matte shot of early cinema (VAZ & BARRON 2004). Unlike early matte shots, we enable free exploration with a 360-degree augmented views of the physical model.

3 Results

The result of including physical occlusion in mobile AR is that intricate visualizations can be embedded within a physical space, such as land-use allocations, design modifications such as expanded developments and greenspace design and dynamic visualizations such as active public transport demonstrations. Our augmentations can interact directly with a physical model, and all of its complex shapes, such as bridges concealed walkways and raised pedestrian overpasses. We demonstrate this with several illustrative cases.

In Figure 2, we present a case study of greenspace proposals on a complex 3D printed architectural model, drawn from a planned urban development of the Pazhou Internet Cluster in Guangzhou, China.

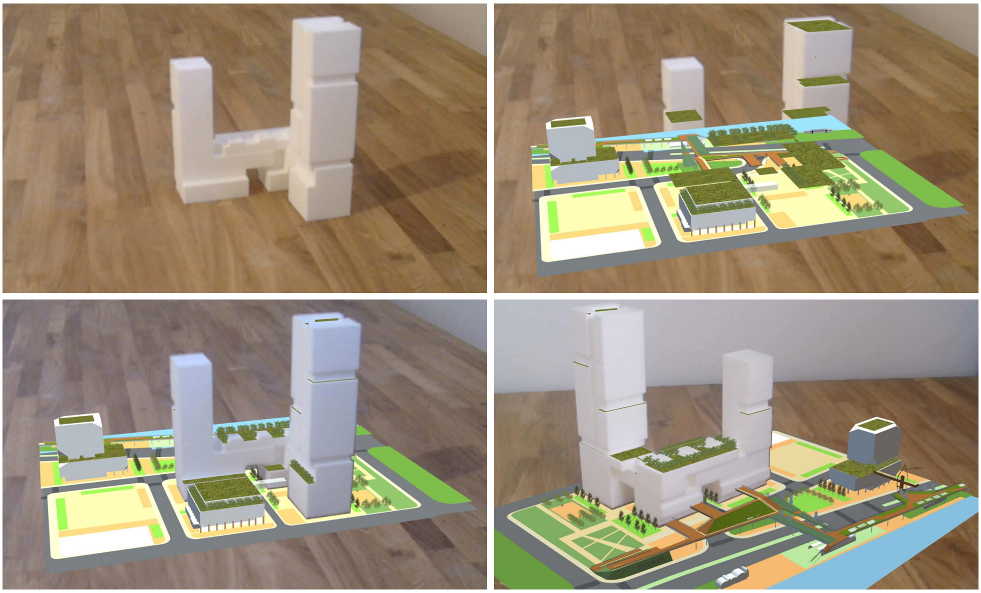

Fig. 2: From top left: The base 3D printed building, the results of standard non-occluded AR for comparison, a physically occluded AR model, and an alternative perspective from the previous overlay

Figure 2 shows a multi-layered visualization, which combines a 3D printed model with the prescribed ground-level greenspace allocations set out in the preliminary masterplan, and further, embed an example design of an urban greening process. The main building has not been replaced by a digital twin and is instead partially augmented, allowing underlying detail to remain visible if required, for instance, to work in tandem with overhead projector augmentation We emphasize the ability to visualize dynamic greenspace designs below and behind structures visible from all angles, such as the ability to view the greenspace design within the walkway from any angle. This would not be possible with previous mobile AR approaches, or overhead-projection based AR approaches.

4 Case Study: Comparative Physical Models for Pazhou Island

Once built, a physical model represents a single snapshot in time of a development's history, limiting its use-case potential, as the urban design progresses. In reality, the level-of-detail and purpose of proposed design changes throughout a project. In the Chinese context, our Pazhou island case study included two important model design stages: the preliminary mas terplan, and the approved masterplan, which is the accumulation of a 3-year design process, incorporating independently designed architectural and greenspace features.

The preliminary masterplan is characterized by a demonstrative low-complexity urban design to illustrate regulatory features, such as the proposed scale of the development area, the architectural height constraints, required building density and desired green space ratio. In contrast, the accepted masterplan contains a comprehensive urban design consisting of complex architect-designed buildings and the surrounding green and blue infrastructure to reflect the long term characteristics of the urban environment.

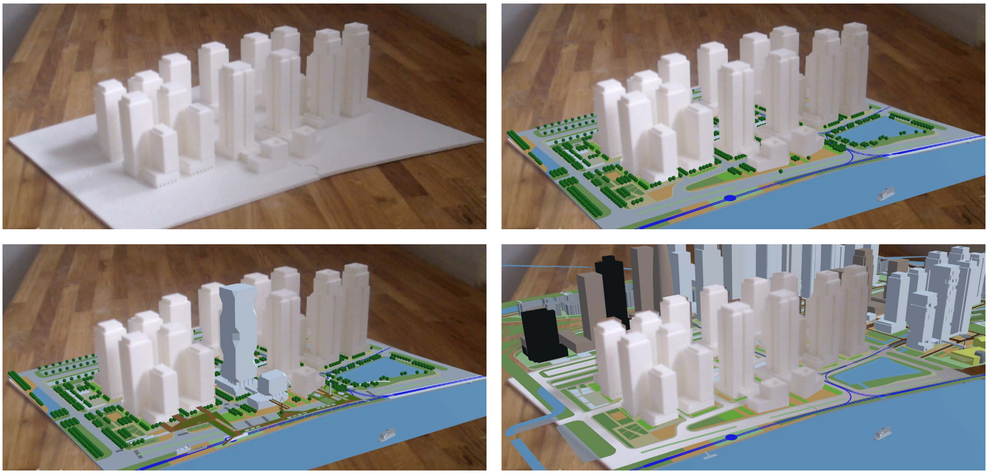

Fig. 3: Top row from left: A 3D printed city block, a Ground plan, transport and greenspace overlay, dynamically replacing physical elements with digital elements, new build city block contextualized within the large scale masterplan

In figure 3, we show the ability of a multiple city block model to evolve and reflect the piecemeal process of real-world large scale development as it evolves in practice. We demonstrate how we can progressively layer street-level space designations, transport connections, and green/blue infrastructure onto the physical model. Figure 3(c) shows the ability to dynamically remove an outdated element, and naturally, situate the updated digital design within the model. Here two buildings have been replaced, and the proposed pedestrian walkway from Figure 2(d) has been incorporated into the riverfront.

This is especially effective in the case of contextualizing new designs within a much larger urban context. In figure 3(d) we show how the evolving elements of the architecturally designed model can be situated within the preliminary masterplan for a single city block and further situate the physical city block into the larger surrounding cityscape. Contextualization of designs in 3D enables a better sense of scale with a surrounding urban context. In Figure 4 we show two urban adaptations to the traffic congestion and water management issues affecting Pazhou island, inspired by designs proposed in BOSSELMANN et al. (2019). Using AR overlays, we can peel back infrastructure layers, and show sub-surface features, such as water storage vaults installed beneath roadways. The ability to interactively showcase rapid 3D design iteration and comparisons to a large audience in real-time is key to adapting AR technology to a workshop setting as a discursive support tool.

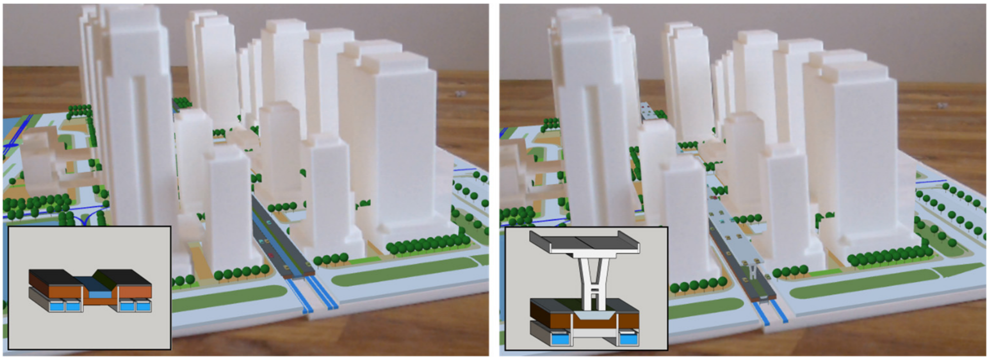

Fig. 4: Comparative intervention visualization, showing a design trade-off between sub-surface water storage capacity and increased transportation capacity

Figure 5 shows an example usage of the mobile AR application during the 2019 Adaptive Urban Transformation workshop. Here we demonstrate successful and robust 3D model tracking in a conference environment, including tracking a white model on a white background. While the application can support several tablets running simultaneously, with each user controlling their own augmentations and viewport, here we demonstrate the role a single tablet can play in delivering an interactive and presentation on future design interventions. A single user was free to explore and toggle future interventions, while the live explorations were streamed to a projector for larger group participation and discussion. The portability of tablets and scalable models makes for a much more portable solution than top-down project-based methods.

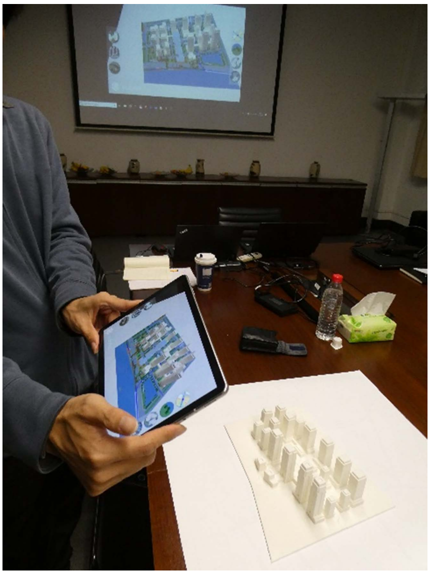

Fig. 5: Using the AR application as part of the Adaptive Urban Transformation project workshop. Real-time user-driven augmentations were streamed to a projector to support group communication

5 Conclusion and Outlook

This iteration in Mobile AR visualization techniques for landscape architecture addresses a variety of drawbacks in previously seen data augmentation methodologies for urban planning and design visualizations. It provides a novel tool to visualize a variety of data and scenarios within and around complex physical models which would not be possible with projected augmentations or previous Mobile AR applications.

Physically occluded visualizations open up new modes of communication and visualization to enhance the widespread practice of model making and could be a flexible tool for designers, students and stakeholders to analyse and communicate evolving or competing designs in a dynamic context. Here we have demonstrated a range of applications. The generic technique could be used in a much broader context, including working in tandem with established methods such as projected augmentations.

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