A Mixed Reality Experience: Advancing Design Decision-Making with Performance Metrics Through Augmented Reality and Physical Media

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Abstract: Augmented reality and virtual reality have effectively served as an immersive environment overlayed within the real world. These experiences are, however, often static and limited in function, primarily, as a full-scale walk-through. This study tests the capabilities of including real-time interactivity and engagement as a tool for dynamic design decision-making. The idea is further explored by integrating landscape performance metrics and project goals to determine how this supplemental data may influence the participants design decision-making. The synchronization of qualitative and quantitative information through a mixed reality experience has major implications to design development as the stakeholder groups have the opportunity of experiencing real-time responses to their engagement of a design project.

Keywords: Augmented reality, virtual reality, landscape performance, design decision-making, parametric modeling

1 Introduction

Through the emergence of landscape performance and the integration of quantitative metrics into outdoor spaces, technology and innovate methods can begin to communicate nature-based benefits as tangible outcomes to comprehend the complex ecological, social, and economic relationships of our complex environments (BECK 2015). Due to the fact that many of these ecosystem services are intangible and abstract, new methods must be explored to effectively communicate these invisible landscape performance outcomes into a perceptual realm for a comprehensive understanding of design decisions (ZHANG et al. 2021). The viability of this process can be explored at both full and reduced scales as a real-time feedback model using a hybridization of augmented reality and physical media; catalysed as a mixed reality (MR) experienced in the p[AR]k.

Through this comprehensive qualitative and quantitative mixed reality process, divergent decision-making, predicated on the information presented in an augmented reality (AR) interface, can be made for multiple responsive and sensible outcomes (LAHAIE 2016). This ultimately generates an immersive, engaging, and interactive design process for a more universal audience to participate in for specific needs from a landscape architecture project, shown in Figure 1.

The modeling of dynamic landscape benefits within a mixed reality experience of both physical demonstration pieces and augmented reality interfaces creates an accessible means to participate in the design development of any project. Augmented reality is not only gaining traction as an innovative representation tool but with the integration of parametric modeling and performance metrics it can also serve as a decision-making tool (DUENSER et al. 2008) to the design process for specific goals and outcomes. With the incorporation of performance metrics into the augmented interface, data becomes responsive to real-time change, performance parameters, and user decision-making.

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Fig. 1: Participants engaging with the p[AR]k through a mixed reality experience of an augmented interface and physical media

2 A Mixed Reality Experience and Workflow

The p[AR]k attempts to model these dynamic landscape benefits within a mixed reality experience of both physical demonstration pieces and augmented reality interfaces to reach a universal audience within a dedicated workstation comprised of a physical sandbox and computational hardware. Augmented reality sandboxes are becoming a common tool to understand topography; however, they are often limited to specific outcomes visualized as coloured heightfields projected on sand media. Although it is beneficial to understand these fundamentals, the computational rigor of these models can be advanced further using parametric software to measure additional terrain characteristics and ecosystem services that include stormwater management, carbon sequestration, and energy savings, shown in Figure 2.

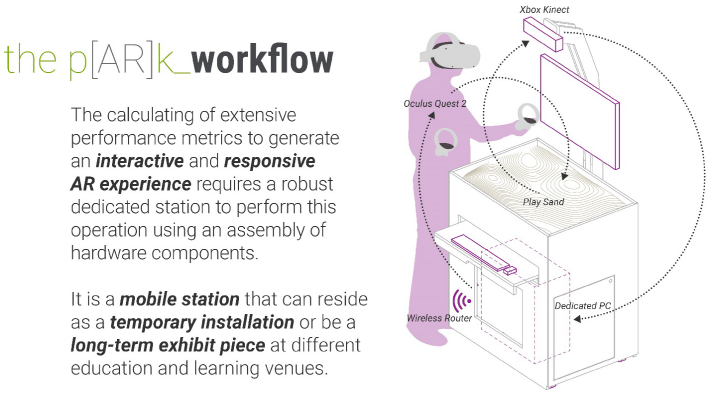

Fig. 2: The p[AR]k workflow between a physical sandbox station and augmented/virtual reality interfaces

Providing visualizations, interactive properties, and tangible media in a mixed reality experience gives the user ownership and agency behind their decisions for outdoor spaces. Professionals, community members, and stakeholder groups can come together and learn the impact of their decisions as their actions are stored in a database for further analysis of communal interests.

2.1 Sandbox Station Capacity

The feedback collected from the point cloud of the sandscape is processed through the parametric modeling software to analyse and generate visuals with charted information based on various parameters. In addition to sand media serving as the terrain model, mobile smart devices, oculus quest controllers, or aruco markers can reference and embed various amenities that include trees, benches, water features, paths and other elements onto the terrain model for a conceptual landscape performance rendition. There are several benefits from this process that include workflow and design development, design-thinking, scenario modeling, trade-offs assessments, landscape performance, and co-creation and collaboration.

In this study, users were put into a hybrid mixed reality experience of physical and augmented reality to address design opportunities within the scope of landscape performance. They were introduced to environment, social, and economic scenario objectives that could be mitigated through the manipulation of a physical sandscape and augmented placement of trees within a hypothetical neighbourhood pop-up park. With this experience, users manipulated the sand topography and moved pieces around, perceiving the impacts different designs had in achieving stormwater management, carbon dioxide (CO2) sequestration, and energy savings. Simultaneously, data readouts from the topography, amenities, and surrounding neighbourhood context communicated quantitative data on the design iterations to assess the trade-offs and performance of different scenario models related to ecosystem services. With each change or addition to this AR model, the data readouts instantly updated to inform next moves within the design decision-making process.

The metrics and formulas for these parametric performance models were configured from metrics and calculators commonly used by allied professions that include iTree's tree benefit calculator, NRCS stormwater calculator, and the US Department of Energy typical household energy consumption. The iTree benefit values used in the different performance scenarios were based on a thirty-year-old healthy honey mesquite tree.

2.2 Performance Objectives

With the influx of real-time quantitative data that updates during this process, there is a profound opportunity to fundamentally shift design thinking and intent from these augmented outcomes. By embedding measurables and metrics to this workflow, this new design process and methodology of a MR experience can potentially emerge that enables the respective parties to generate robust design strategies for evaluation on specific goals and objectives. As part of this performative MR experience, the interface can be configured to display data readouts communicating quantitative information throughout the design process to assess the trade-offs of different scenarios as a divergent process (CIRULIS & BRIGMANIS 2013).

There are many different AR programs available for users to immerse themselves within a designed space, however, the values most programs don't provide is the ability to synchronize it to an industry standard modeling software such as 3D Rhinoceros to further refine a design concept. This is made possible with the plugin additions of Grasshopper (parametric modeling) and Fologram (AR platform) to create a real-time feedback between the perceptual AR interface and the cognitive modeling software. Grasshopper manages and integrates the tangible and intangible analytics for performative landscapes while establishing a dialogue with the Fologram application on a smart device. Fologram is then used to engage with the design model using either finger gestures on a touch screen or by scanning printed aruco

markers, referencing different design elements such as trees, pavers, or benches. The programs in tandem create a responsive workflow of reciprocating outcomes based on the decision-making process of the user. The perceptual experience created can be viewed simultaneously on the computer and in the physical world, blending the two in a hybridized environment.

Within the p[AR]k project experience, users were evaluated on two different scenarios to determine if performance objective and metrics impacted their decision making. In the first scenario, users were only required to manipulate the p[AR]k space through a perceptual lense of only seeing the site as qualitative and figural with landforms, water features, and tree plantings. In the second scenario the users were provided different landscape performance objectives that integrated and displayed quantified metrics to determine if and how this may impact their design decision-making any differently. Performance scenarios included managing stormwater runoff, sequestering CO2, and reducing energy consumption from buildings.

2.3 Performance Methods

For the stormwater runoff scenario, the surrounding impervious conditions of streets, sidewalks and buildings coupled with the park's landforms contributed to a calculated stormwater runoff volume from a typical 0.5" rain event. This volume served as a baseline objective to manage through a catchment system (landscape depression) and trees. The runoff from those landform conditions were conveyed through drainage lines, suggesting the most optimal location to place trees to intercept the runoff. In the carbon sequestration scenario, the EPA's metric for an average typical passenger vehicle emitting about 4.6 metric tons of carbon dioxide per year, or 10,141 pounds of CO2, was used to establish a site measurement for the surrounding neighbourhood context. And according to the U.S. Department of Transportation, the average number of cars owned per household is about 1.88. Based on these statistics, the surrounding residential households contributed a total of 247,853 pounds of carbon emissions annually. Lastly, the energy savings scenario used the U.S. Energy Information Administration's average household consumption metric of 10,715 kilowatt hours annually.

Users were first expected to manipulate the topography to create dynamic landforms and water features within the neighbourhood pop-up park, see Figure 3. This would ultimately impact stormwater runoff potential while simultaneously creating drainage and catchment

Fig. 3: Visual example of the stormwater management scenario

systems in the landscape. The participant quickly realized that either one large or multiple intermediate catchment systems within the topography could not contain the site's runoff alone and would also require the strategic placement of trees to help with the mitigation process through interception.

Trees can intercept runoff through both their tree canopy and root structure. For the modeling and calculation process, the tree's ability to intercept runoff from their root structure was used and would be assessed on its performance based on its proximity to the generated drainage lines in the topography. As the user realized this in their tree placement, they began to strategically place trees within close proximity to the visualized drainage lines in order to maximize their interception potential leading to a higher percentage of managed runoff.

The design of the neighbourhood pop-up park for CO2 sequestration was more ambiguous leading to less consistent tree placement strategy since this is a non-point source pollution. In these types of situations, it was found during the study that when there are unclear demarcations for tree placement users would often place trees with less reason or logic into the landscape, shown in Figure 4. This did, however, lead to users manipulating the sandscape topography to have less area dedicated to catchment basins so that more trees could be placed.

Fig. 4: Visual example of the carbon dioxide sequestration scenario

Tree placement within the energy savings scenario had similar results to the stormwater management one in that as users realized the relationship of a tree's location to a building would reduce its energy use, their strategic planting gravitated towards those specific parameters. With the energy savings, tree distance and orientation to the building would result in different kilowatt hours saved. This can be seen in the tree and building values in Figure 5.

For example, a tree in near proximity to the north facing façade of a building would be less beneficial to a marginally further distanced tree from the south facing façade since that sun facing façade would be absorbing the most, requiring more tree shade protection to reduce the building HVAC use.

The combination of the responsive interface, the ability to co-create and engage with different stakeholder groups, and the real-time integration of data can fundamentally reroute the design thinking methods. Abstract and formal ideas can merge into one process, helping the user engage, innovate, increase options, and see the implications of those decisions simultaneously with their collaborators as a cyclical feedback loop.

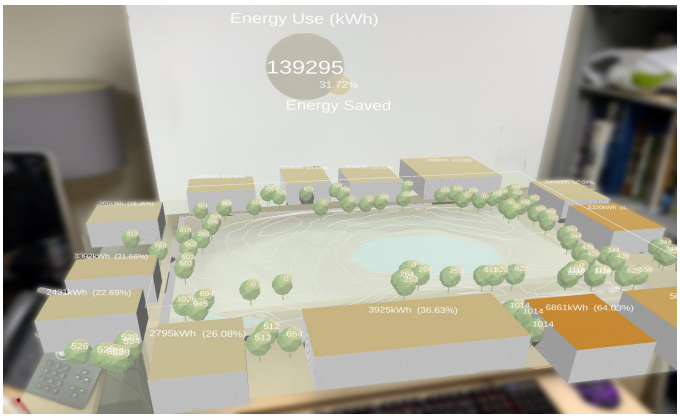

Fig. 5: Visual example of the energy savings scenario

3 Results

After users participated in this study through the p[AR]k, they were provided a survey to assess if and how the integration of landscape performance metrics (quantitative information) impacted their design decision-making (qualitative information). Out of this beta testing group of roughly thirty undergraduate landscape architecture students, one hundred percent agreed that the inclusion of landscape performance values impacted their design decision-making, as asked in the first survey question. This broad overview of landscape performance metrics were followed-up with more specific performance questions to determine which ones did or did not have a significant impact on their design decision-making, provided in the below figures.

3.1 Design Decision-Making Outcomes

Following the first survey question, the first landscape performance question in Figure 6 asked the user to rate how significant the inclusion of performance metrics was to their design decision-making. A scale of 1 to 5 (x-axis) was used where 1 meant no significance and

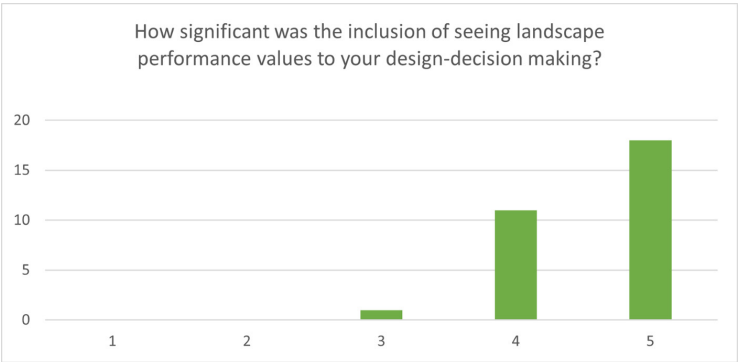

Fig. 6: Survey results on the significance of integrating quantitative landscape performance metrics into the design workflow process

5 meant major significance. The number of results (y-axis) shows the majority found it within the high significance range.

The next performance question in Figure 7 asked which landscape performance scenario was of value to the user. The scenarios were specifically diversified to reflect environmental, social, and economic values. The participant could select multiple options so many users found multiple performance scenarios to be important to them.

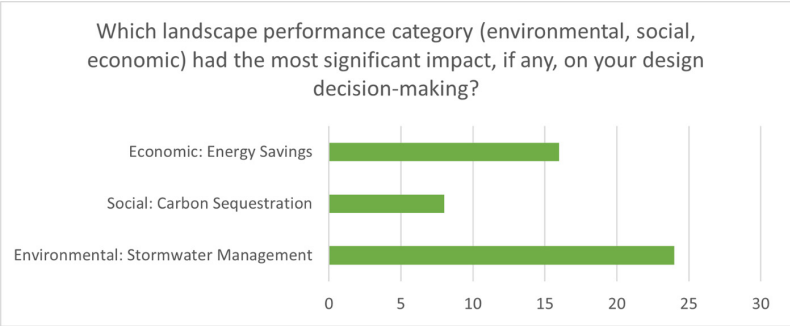

Fig. 7: Survey results on the significance of the different landscape performance scenarios

The last performance question in Figure 8 asks for the significance in designing towards a specific goal. This question also used a scale ranking of 1 to 5 was used where 1 meant no significance and 5 meant major significance. This clearly indicated that establishing performance goals for individuals drove their design decision-making.

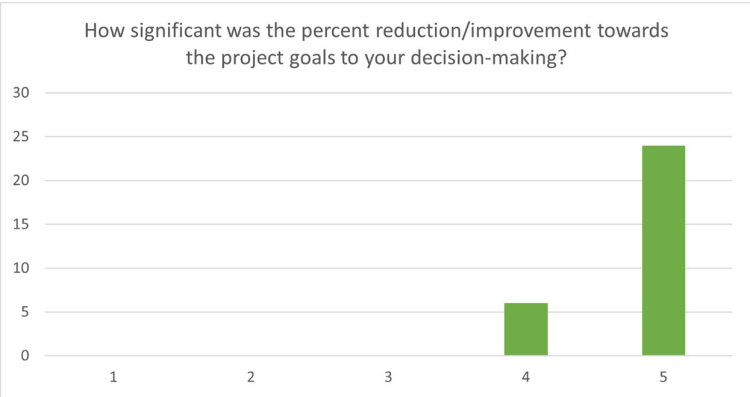

Fig. 8: Survey results on the impact project goals had on the design decision-making process

4 Conclusion and Outlook

This mixed reality provides an advanced learning experience for the user to engage with innovative technology, create robust analytical modeling and assessments, and create a par-

ticipatory decision-making experience to advocate for healthy sustainable cities (WANG et al. 2013). The hybridization between malleable model making with augmented data reveals a symbiotic connection of instrumental tools in design thinking. It correlates with many STEM related principles of evidenced-based strategies where design can act as a strategic response to problematic issues of flooding, public health, and equitable resources within the built environment.

This mixed reality design experience has tremendous potential to increase the capacity for users, designers, and the community to work together and advocate for healthy living environments, make design more efficient by linking tools that help speed up the process, and helps everyone involved see the benefits of proposed designs (LIU & WANG 2019). Augmented Reality has shown to serve as an innovative and versatile tool to visually communicate information as part of an analytical and design narrative for more informed design decision-making. This MR experience and workflow can further separate itself from other methods in the immersion and perception of space as it overlays qualitative and quantitative information impacting the composition and performance of a design concept. Rarely is it possible to experience the data that binds ecologies together. AR still contains limitations to this progressive design approach, however, it can begin to give a glimpse of these interactions and relationships between systems in real-time as designers augment space into a mixed-reality.

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