Architectural User Interface: Synthesizing Augmented Reality and Architecture

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Design methods and digital/spatial environments that combine augmented reality (AR) and architecture are presented, with particular focus on synthecizing a novel design process. The architectural brief is an archeological museum/excavation site that directly confronts issues of occupation, circulation, form, and large archives of data. Combining the efforts of twelve architectural designers with a team of AR developers, a taxonomy is developed of affordances, feedback mechanisms, and output/display options. This taxonomy constitutes preliminary usability heuristics for an architectural user interface synthesising AR and architecture.

Introduction

Active research has been conducted on Augmented Reality and Virtual Reality in computer science since the 1970s. Until recently, latency and registration issues significantly limited AR implementations to low-resolution registered images or handheld applications at arm's length. But advances in head mounted displays and software have made the use of AR feasible in widely expanded contexts and content.

In architectural design, AR is of particular interest because it is inevitably spatial and suggestive of an emergent interface, marrying space and information. The release of advanced and accessible AR devices (e.g. Hololens, ARKit) has provided the opportunity to transform both the architectural design process and introduce new interactive hybrid spaces that are infused and organized by information .

Within computer science, AR is assumed to adapt to any spatial settings. However, designing AR applications and architectural settings together will allow for exploration of a full range of affordances, feedback mechanism and output/display options, leading to a generalized set of usability heuristics. It can exemplify embodied interaction [1] and address the historical emphasis on symbolic systems that ignores the importance of the social and architectural setting. Thus, an understanding of architectural space and place is not circumstantial, but rather essential to how interaction can be meaningful to users.

In this paper, we present design research focused on creating architectural space that takes full advantage of AR. The design setting presents challenges both architecturally and the integration of very large data archives. The Mount Zion Archaeological Park in Jerusalem is the site of archaeological excavations close to completion and the design for a museum and park preserving and explaining the site is contemplated. Huge amount of data have been generated during the eight years of the excavation (objects, locations, temporal) extending to the larger archaeological record across the middle east and the world.

Our team of twelve architectural designers, three computational designers, and faculty from departments of architecture, archeology, and computer science engaged the process of designing tightly coupled AR interactions and architectural spaces.

Our design process started in a conventional architectural manner, gathering information about the site and program. Applying spatial and informational requirements for an archeological museum, we developed AR applications, generating alternate museum designs with embedded AR interactions.

1. Lessons learned from the process of combining normative interaction and architectural design practices evolves a hybrid design process.
2. Due to a series of challenges in combining architectural representation and interaction design, we developed novel tools that allow for exploration of architectural spaces using traditional architectural views (plan and perspective) as well as to interact with and understand AR.
3. We describe designs for an interactive archeological museum and discuss how designers proposed new architectural spaces and AR interactions.
4. Finally, we offer our taxonomy of AR interactions that can serve as a template for future design.

Literature Review

The interest in the use of AR in architecture has focused primarily on applications during design, construction, and post completion. Technologies including GPS, cloud computing, and mobile computing are potentially important ways of advancing the construction process, exploring various aspects including design collaboration, construction, visualization, and education [2,3]. Head-mounted AR systems can be used during the architecture renovation process [4] and to visualize designs of a building, modifications to a building, and extensions to a building in an outdoor environment [5]. The goal of our work is to extend the use of AR not solely as a tool for design but as a medium.

Research on the use of AR technology in learning situations applicable to architecture focuses on general principles including challenging, gamification and curiosity. [6] as well as superior spatial understanding using interactive 3D models using AR versus printed plans. Our research will build on this type of insight by allowing designers to test AR interactions during the design process and combine them with spatial elements.

Work from media studies situates AR in a broader cultural and historical context. [7] Any understanding of the use of AR must include how it compares with existing methods of engagement. MNEMOSYNE is a system that delivers a personalized, interactive multimedia experience to museum visitors through the use of computer vision [8]. Although AR will differ technologically, the issue of personalization is central to its use. The Transformative Museum project [9] is an important framework for this understanding in a broad context.

The development of AR applications in architectural and urban settings has increased with these expanded technical capabilities. Earlier attempts to embed AR into architectural and urban environments [4] integrated salient elements of the Hololens system but in a form requiring cumbersome hardware.

Our work with embodied architecture takes advantage of AR for visualizing and collaborating during design process. However, we go beyond using AR as a tool and focus on how AR can transform architectural spaces as a medium.

A New Architectural Design Process

We employed design research methods that generate knowledge and insight of complex problems by the process of design [10]; multiple designs can serve to uncover an expanded range of possibilities. Our team included architectural designers, computational designers, and faculty from architecture and computer science. Our process resulted in twelve designs, each of which proposed a specific architectural form and use of AR.

Our work started by trying to address the development of the architectural space as a separate issue from the AR interaction design. However, designing architectural space that takes full advantage of AR requires a process that is different than either architecture or interaction design alone. To address this issue, we first conducted precedent studies of AR technology, archeological museums, as well as the rare examples of AR integration into architecture. Using these precedent studies, we developed a list of required spaces for an archeological museum as well as a list of potential AR interactions. Each designer then was free to create innovative spaces integrating AR technology seamlessly.

Creating AR was challenging for architects who are mostly trained in creation of form and static space and have little experience in interaction design. To rectify this problem, we experimented with integrating various prototyping and diagramming methods within the architectural design process. This required an iterative process of architecture and interaction design. As the architects made progress in developing spaces and programs for the museum, they also developed scenarios for re-inventing the ways archeological information would be embedded using AR.

We evaluated the architectural designs using both normative architectural evaluations methods (static categories including geometry, circulation, views, lighting, enclosure) as well as interaction evaluation (shifting views over time or multiple users). AR interactions began with storyboards, then generating spatial diagrams to situate AR interaction (the analog step). Next, we used storytelling by the designers to both conceptualize architecture/AR synthesis. We created an interactive desktop application prototype that would allow simultaneous exploration of architectural design and AR interactions (the digital step).

The analog step started with each architecture designer brainstorming methods to integrate AR within their architecture as they developed their designs. At this stage we specifically did not focus on limitations of current technologies. Each designer developed diagrams and models creating a fulsome descriptions of their proposed AR integrations. and storyboards combining AR with space (Figure 1) either by hand sketching or using familiar sketching software. These storyboards proved to be more useful in communicating innovations but they lacked detailed spatial information. Therefore we decided on a "spatial storyboard" technique which consists of schematic maps that are accompanied by flow charts of interactions linked space (Figure 2).

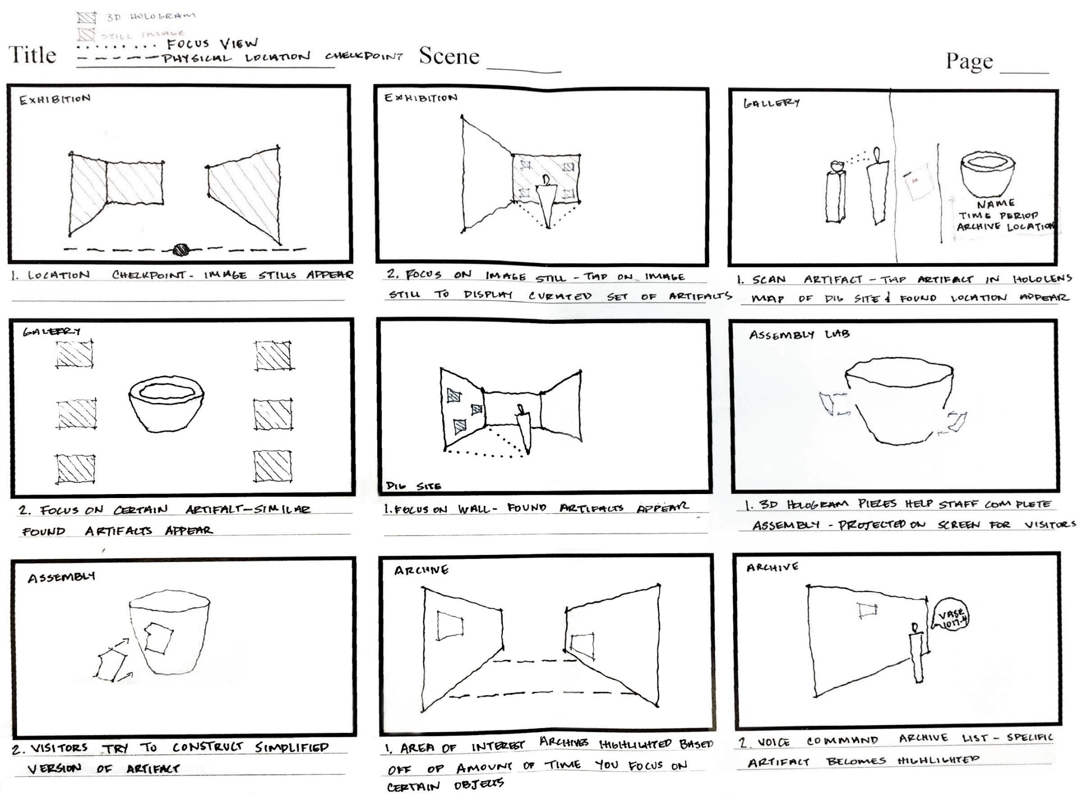

Figure 1. Hand sketched storyboard combining AR with space

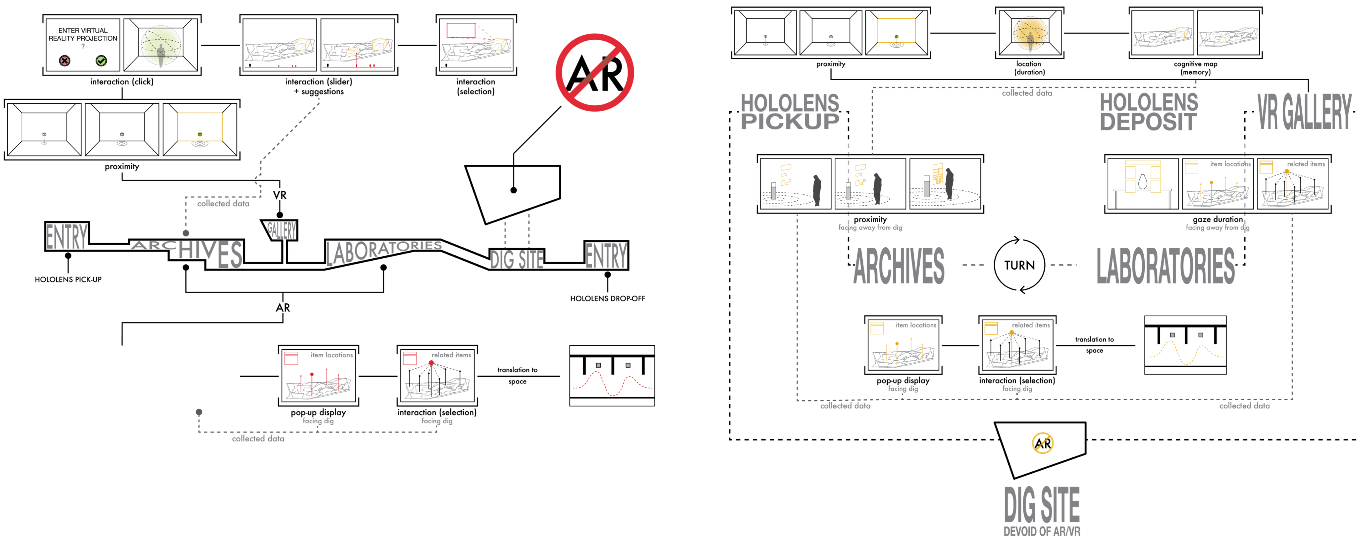

Figure 2. “Spatial Storyboard”, a combination of storyboards, linked spaces and their interactions.

At this stage, based on all the AR proposals, we were able to develop a preliminary list of different categories of interactions that could be shared between designers. The computational designers then developed sample interactions for the Hololens based on the proposals made by architectural designers (Figure 3). The modelling of the 3D artifacts was completed in Rhino3D (https://www.rhino3d.com/) and the programming of the Hololens was in Unity3D using the C# programming language. This marked the beginning of our digital stage.

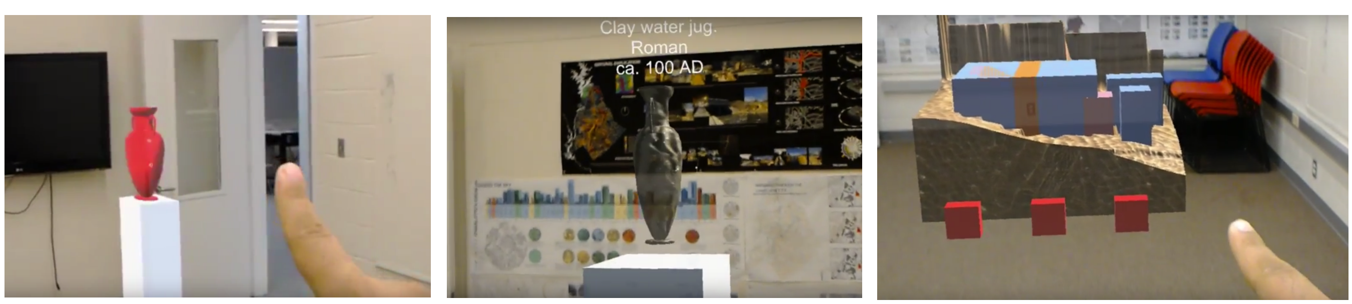

Figure 3. Preliminary testing of AR interactions designed by architects using the Hololens.

Testing with the Hololens proved helpful for the architectural designers to better understand the role of AR in their designs. However, there was still a large gap between what the architects envisioned for their buildings and how AR would integrate within it. More specifically, it was impossible to show the huge amount of building details developed by the architects using software such as Autodesk Revit as part of the AR experience. So our team created an alternative method to represent the AR and the space in which these interactions take place in. The results of our work was an interface (Figure 1, Right) that enables users to explore proposals as well as to simulate the AR interactions. More specifically, the interface would enable us to import 3D models of buildings and create a walkthrough in the proposed space, as well as to embed the proposed interactions. Our interface allows users to view the space in both perspective and top view which are conventional views from any architecture representation and interact with proposed AR objects and information. It also consists of complementary views that show a user's interaction log and finally a view highlighting different AR interactions as a user experiences a proposed intersection of AR and architectural space. The interface was useful both for the designers and for critics who regularly reviewed the designs. Together these views allow anyone to explore each proposed museum design and evaluate its potential as an interface. It also allowed the generation of videos for each project that demonstrated both the architectural space and interaction simultaneously to help with heuristic evaluations (Figure 4).

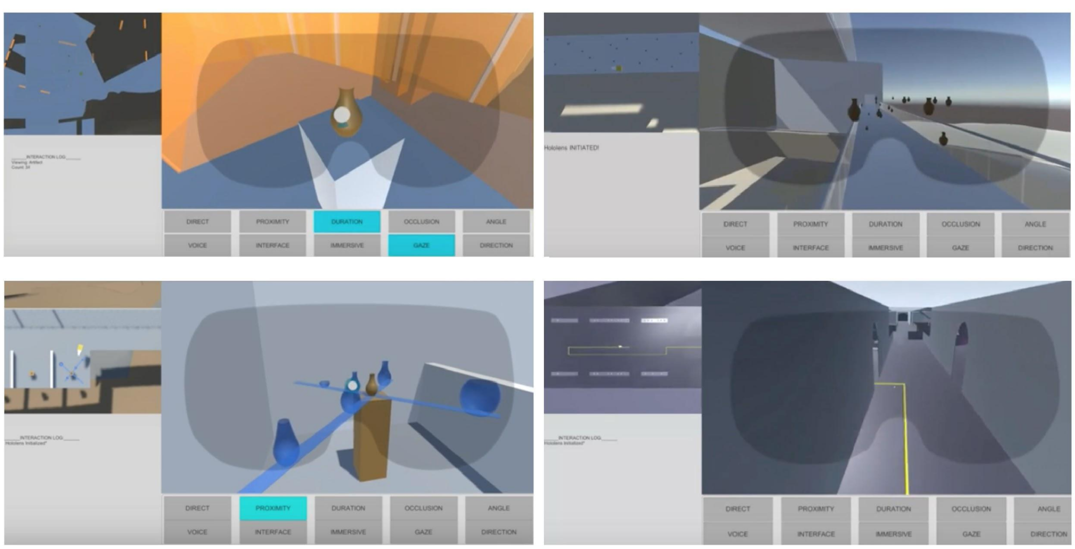

Figure 4. Case studies showing architectural setting and interactions simultaneously.

Experiments with the interface allowed our team to refine the different affordances to fit best with a designer's vision and to easily implement and prototype the proposed interaction affordances for Microsoft Hololens. A taxonomy was developed from these experiments and became available to all designers. (Figure 5) shows a diagram of our process which can be used as a baseline for future designs of architecture and AR.

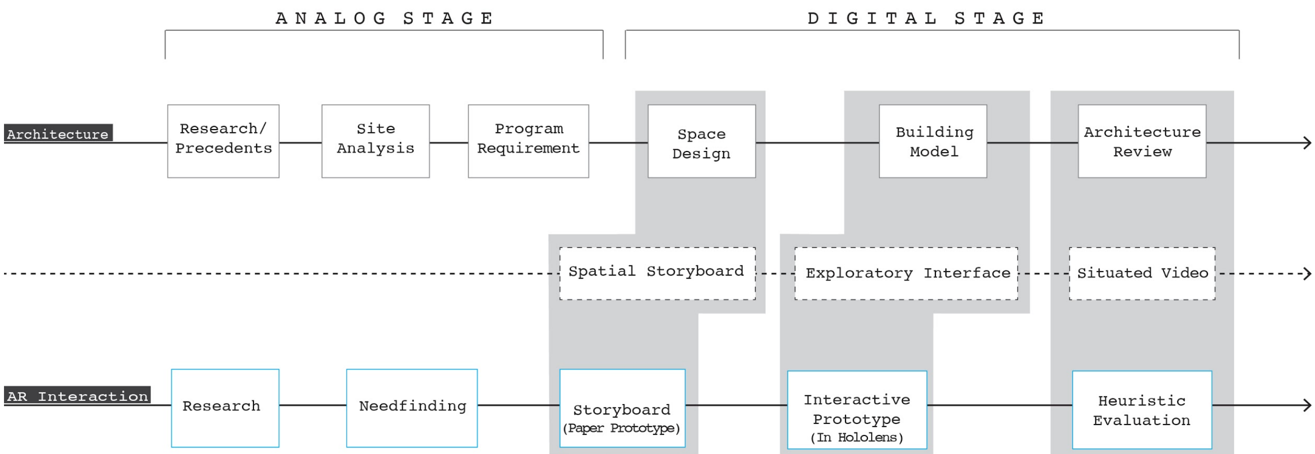

Figure 5. Proposed process of hybrid Architecture and AR.

Designs for an Archeological Museum

Twelve architectural designers created designs that illustrate the range of AR and architectural approaches, demonstrating of how this process can yield new types of architectural spaces (complete documentation at www.xxxxxxxxxxi).

The architectural program included preservation of the archeological excavation, a gallery featuring selected artifact from the site, an extensive archive of artifacts discovered on the site and a suite of offices and research laboratories for research.

Beginning with the same requirements and site, architectural designers produced a wide range of different spaces with embodied AR. However, there were similarities; the most common overlaying **text** on artifacts, although the way the information is triggered and interacted with differs. One project describes the proposed building as: *"... a pathway around the dig site. The artifacts are displayed in a linear gallery. When the users have the Hololens on, related to their **proximity** to the artifacts different levels of **overview/detailed** information* *is presented to describe the artifact, and the related location will be highlighted in the dig site."* This work presents information triggered based on **proximity** of users to each physical object, a feature employed by many of architectural designers.

With the goal of exposing the context of the artifacts to the users, another designer chose to include **virtual** landscape **spaces** from different eras when are in **proximity** to physical artifacts in the galleries. Furthermore, as users explore the dig site, AR reconstructions of structures that existed over time are revealed: *"The building includes two masses stand on each side of the archaeological dig in order to maintain a visual connection with the archaeological dig. The Hololens primarily is being used to display* ***text*** *on artifacts, recreations of artifacts, and* ***virtual objects*** *recreating historical buildings in their specific location on site, and* ***virtual*** *landscape* ***spaces*** *of Jerusalem throughout historical time periods."* (Figure 6)

Figure 6. Virtual space in the larger city.

Not all designers chose to overlay **text** on physical artifacts. Through fusing data visualization with a central dome, one designer used **gaze target** as a means of interacting with a point cloud visualization. She describes the users' experience as: *"users will enter a domed space, where they will interact with a point cloud that represents the quantity of data* *in the site. The point cloud is color coded by era, to help the user understand and handle the amount of information. The interaction starts by* ***gaze targe****t. As the* ***gaze duration*** *lingers on a point in space, the display expands and* ***virtual objects*** *and* ***text*** *are presented.* ***X-ray*** *views to important city sites occur at the end of each corridor."* (Figure 7)

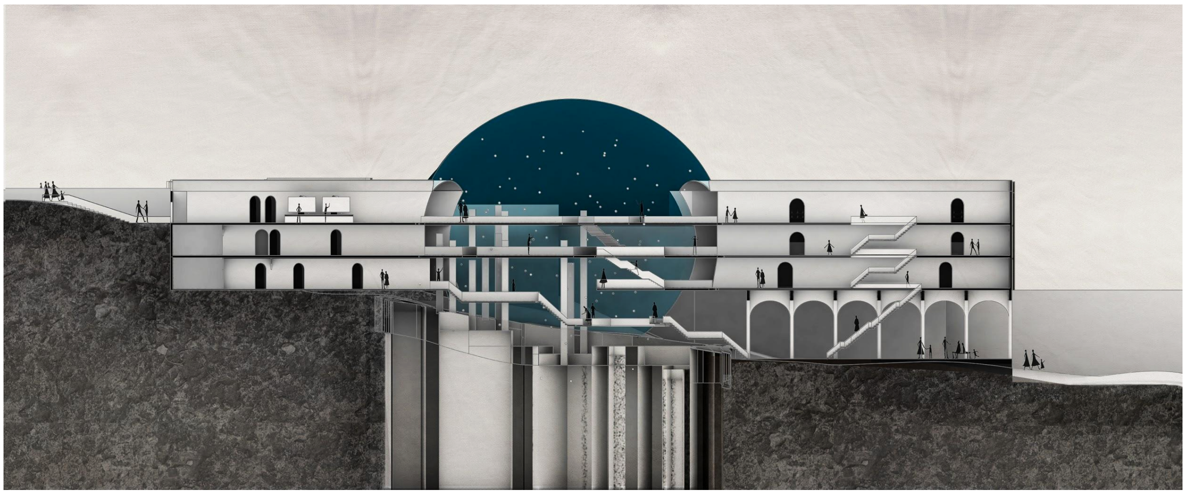

Figure 7. Data visualization with gaze target/duration.

A number of designers used AR to display personalized **wayfinding** throughout their buildings. One proposes using **voice** input from multiple users to create a "curated shared experience" by including **virtual walls** to guide users in a gallery: *"Most of the AR experiences happens in a rectangular gallery space. The unique interaction is a shared experience of the users through multiple voices. Based on analysis of these voices, a navigation path will be highlighted with* ***virtual*** *walls, filling the space with desired artifacts. In this approach, the technology allows for a dynamic experience that is shaped through the dialog between visitors as well as interaction with the objects. The* ***virtual objects*** *organize the collection into a* ***virtual space*** *based on the visitors' dialogues."* (Figure 8)

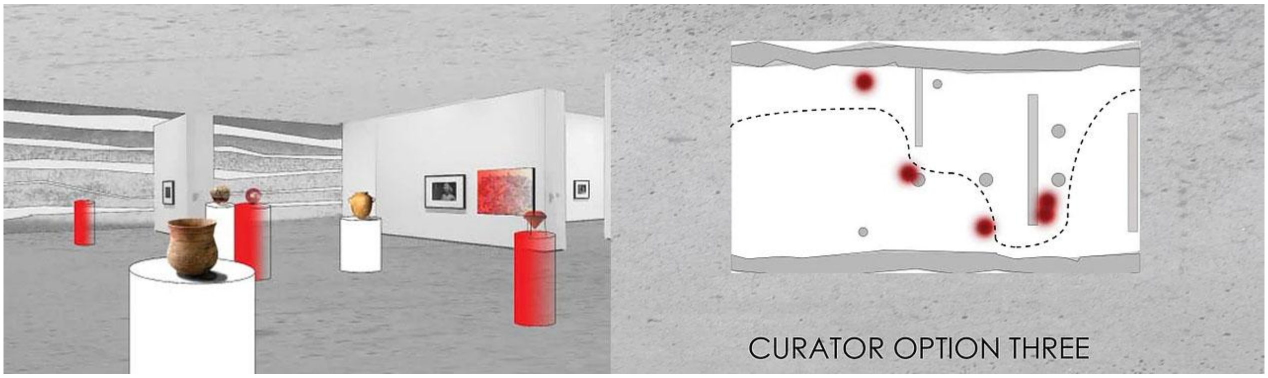

Figure 8. Virtual Objects added to architectural setting.

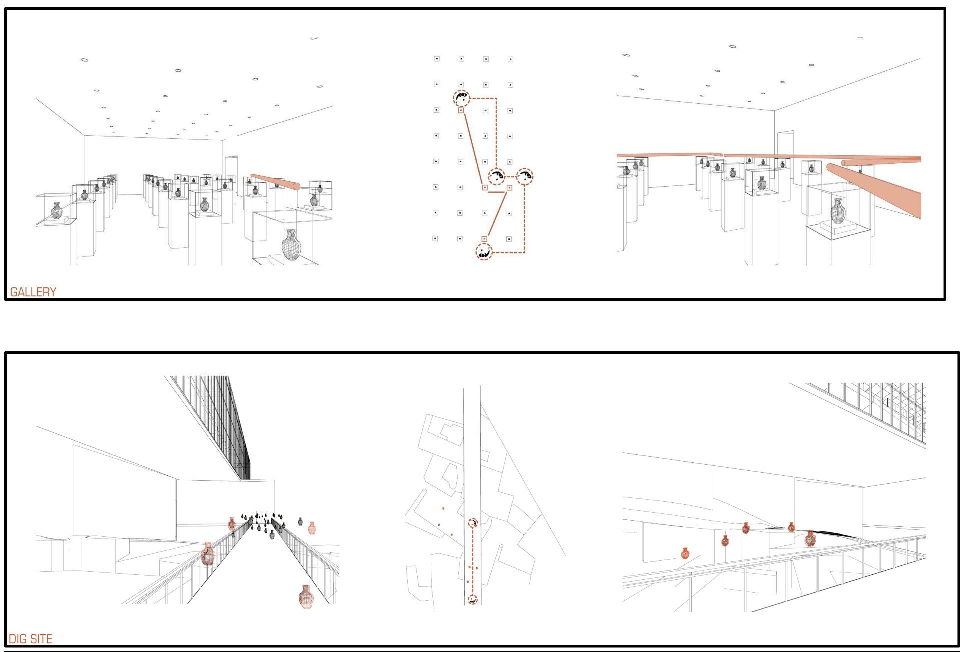

Figure 9. Gallery and bridge over excavation; wayfinding, orientation control.

One designer proposed a pathway over the digsite, connecting gallery space to the archive located on opposite sides of the site, combining **text** in the gallery with **virtual objects** in the digsite: *"...In the gallery space, the artifacts are displayed in pedestals. Based on user's* ***proximity****,* ***text*** *is displayed and similar* ***virtual objects*** *will appear in the same space. As the visitor proceeds over the dig site, the* ***virtual objects*** *that float above the pathway will move into place of the exact location they were found, based on the* ***angle of view*** *on the pathway.* ***Physical computing*** *is activated in the archives, opening drawers/cabinets that match a user's interests."* (Figure 9)

Designers also proposed usage of AR to construct dynamic **virtual spaces** that allow a group's experience to change based on users' preferences or searches: *"The building rises from the dig site, surrounded by gallery spaces in upper levels, creating relationships between the two spaces. In the gallery space* ***text*** *will offer the visitors information about the artifacts they view, based on* ***proximity*** *and user preferences. The user can use* ***hand gestures*** *to search based era, type and value of the artifacts. This will result in* ***virtual partitions*** *that group artifacts together to direct visitors to their desired search results. In turn, the galleries* ***virtual space*** *becomes a dynamic component in the museum experience, creating a continually evolving experience."* (Figure 10)

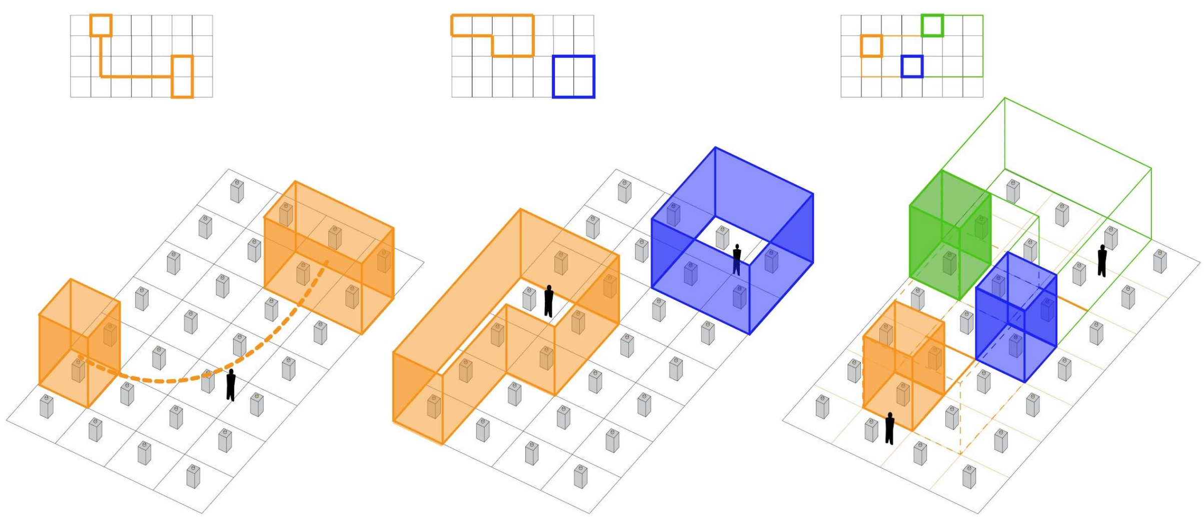

Figure 10. Virtual walls dynamically displayed.

Architectural User Interface

Based on design studies, a set of connections between the architecture interface and AR evolved and were compiled into a taxonomy of possibilities based on inputs (afforded and interactive) and outputs (display and physical).

Afforded or passive inputs are those that because of physical or cultural factors are understood without need for visual feedback.

- **proximity**, moving closer to or further alter the data display
- **gaze target**, Gaze direction immediately understood
- **gaze duration,** Duration is learned after brief use
- The **orientation** that a user faces is apparent in two ways; inside/outside works if the architecture makes it obvious; geometric orientation obvious when the architectural arrangement is strongly geometric.

Interactive inputs require some feedback to make it cognitively present.

- **view direction**: head motion can be understood as an input in either the vertical or horizontal direction.
- **hand gesture**: Hololens' finger or hand gesture require significant feedback
- **voice**: voice recognition can be used to provide rich input; needs periodic feedback

The output of the architectural/AR system can assume either display or physical aspects.

- **physical computing**: rearrangement of physical objects
- **overview/detail**: details made to appear to come closer to user and be available for inspection
- **transparent/opaque**: virtual walls can be selectively closed and opened
- **"X-ray vision"**: display that appear to allow users to see into other spaces
- **virtual space**: generated user moves through space, guiding or circumscribing
- **heat map:** show the locations of classes of objects.
- **cognitive maps:** capture individual interest and present
- **text**: explanatory text appears and transforms with user movement.
- **virtual objects:** appear in space to connect diffuse objects
- **wayfinding:** created to guide users

Equally important to specific affordances is the change to the way that architectural space must be conceptualised and understood. The normative standards of architectural design, emphasizing geometric clarity, simplicity or uniqueness, will be less important than the ways in which places connect with the meaningful activities of the users. For architects, programming human occupation is almost always understood as preliminary to the creation of form and geometry. Our work emphasizes the importance of embodying users actions as part of the medium.

In the work of the designers on this project, heuristic evaluations by teams of experts consistently found significant experimentation with unique architectural forms that provided important and novel ways to engage with AR. One measure of this innovation is the surprising forms of the design solution that would be difficult to understand without an appreciation of the affordances of AR combined with spatial and architectural logics. In at least a provisional way, they provide a foretelling of the embodiment called for by Dourish and others [1].

During our design process, our goal of creating architectural spaces that take advantage of AR requires a rethinking of traditional architectural and interaction design methods and how these designs are represented. We developed an interface that allows for simultaneous exploration of architectural space and AR interactions. However, creating such interface requires more efforts in usability studies and development, as well as more interoperability between architectural design software and this interface.

Our work has used Hololens but it could apply more broadly to any form of AR. For, if AR aims to create new forms of interactions that engage both technological and social factors, design methods must be able to represent both the architectural setting and information interaction simultaneously. This will involve expanding and transforming methods both in HCI and in architectural design. Otherwise they will remain separate from the life of the places they occupy.

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