Towards Mixed Reality Architecture

Context-Specific Design Approach for Mixed Reality Environments

by

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Abstract

The more we dwell in cyberspace through our digital devices, the more disconnected we are becoming from the real world, entering a future where people's prolonged inhabitation within virtual environments could potentially turn major functional aspects of the built environment and its architecture obsolete. Our homes, offices, and other places in our cities will have to compete with virtual replacements for people's time, money, and value. Extended reality technologies can be used to design and build cybernetic architecture to prepare for such a future. So far, architects and designers have done little exploration of this emerging practice.

This research seeks an expanded role of the built environment inside mixed reality experiences, proposing a Context-Specific Design approach to mixed reality development that is designed for and with the architecture in which it is situated. The proposed approach allows for a thoughtful and tailored inclusion of spatial elements such as floor, ceiling, walls, furniture, and objects, posing as an alternative to the commonly adopted modular design approach to mixed reality environments, which disregards the qualities of the place and its architecture.

The thesis follows Research through Design and Speculative Design as methodologies for producing a series of prototypes and a functional mock-up of a retail space made as a mixed reality environment. Some design concepts, methods, techniques, and learnings emerge as core research findings.

This research furthers the discussion on the use of extended reality in architecture by proposing a new use case for mixed reality. It also contributes to the emerging practices of cybernetic architecture and media architecture.

Keywords: Mixed Reality, Architecture, Spatial Design, Cybernetic Architecture, Media Architecture, Interactivity, User Experience Design, Phygital

Land Acknowledgement

I want to acknowledge the Mississaugas of the Credit, the Anishinaabeg, the Chippewa, the Haudenosaunee, and the Wendat peoples, who are the original custodians of the land where I live, work, and create.

I, too, come from a land that was also once colonized and displaced my ancestors from their homes, fracturing and injuring their culture and identity. For me, land acknowledgments are key to recognizing and reconciling with the harm and hurt of our collective past.

Acknowledging the land's original custodians is important because it keeps the history of indigenous people present and alive in our work. It helps us counteract centuries of deeply systemic and institutional suppression and erasure of First Nations.

As an international student who created this project in Toronto, Canada, I believe it is important to address the history of the land. This is also because land is fundamental to the practice of designing the built environment. This project, in particular, looks at the potential future of the built environment, emphasizing the importance of architecture and its context in an increasingly virtual world. The project also places importance on the values of place, context, and people's relationship with it.

Acknowledgement

I am immensely grateful to all those who provided direct and indirect support throughout my project. I am particularly thankful for the opportunity to access emerging technologies and delve into various theories through my studies at the Digital Futures Graduate program, which opened a new world of possibilities for me. The lessons I learned from my classes and my cohort have been invaluable.

These experiences have profoundly transformed my worldview and will continue to influence my practice in the future.

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01. INTRODUCTION

1.1 An overview

This research lies at the intersection of extended reality (XR) technologies, architecture, and experiential retail. It explores how spatial features of a built environment can be integrated inside a mixed reality (MR) environment to create a unified real-virtual place unique to its architectural design. It uses MR technology to manipulate our experience of the built environment. It does this by proposing a design approach termed 'Context-specific design' that draws on methods and concepts from the field of architecture to create a unique blended environment.

1.2 A problem = An opportunity

Steven Spielberg's movie *Ready Player One* (2018) is set in the year 2045 and pictures a possible future where people regularly use advanced XR technology to escape reality and live in the 'Oasis,' a virtual universe of sophisticated virtual worlds. An aerial view of this dystopian future reveals the built environment, a wasteland, and a vertical ghetto comprising cramped makeshift metal structures stacked with camping trailers and littered with electronic equipment. Since people prefer to do everything in the Oasis over the real world, the built environment seems to have degraded and reduced, only to serve to compensate for the biological bodily functions.

Image 1: An aerial view of the built environment as shown in the movie Ready Player One by Steven Spielberg (Giardina, 2019)

This sci-fiction movie paints a picture of a future close to the current trajectory of virtual reality technology and the development of Web 3.0 platforms like the Metaverse. People's inclination towards spending long hours in cyberspace, such as social media platforms, and replacing physical spaces with virtual alternatives like virtual meeting rooms point towards a cybernetic paradigm. We are becoming disconnected from our real-physical environment, and the role of the built environment is rapidly changing to adapt to our virtual lives. At the same time, cyberspace is evolving into virtual architectural spaces that allow shared and embodied spatial experiences using VR technology. An example of such cybernetic architecture is the Metadistillery José Cuervo, a project by Rojkind Arquitectos located in the Metaverse.

As the virtual environments of cyberspace become more sophisticated, more functions of the built environment, along with the time, value, and money spent on building and maintaining it, will shift to virtual environments. Does this mean we will have to choose between the Real and the Virtual? Not entirely, because virtuality exists on a continuum (Milgram et al., 1994) and mixed reality technology can be used to virtually enhance the built environment's physical architecture, creating blended real-virtual places. Hence, similar to the cybernetic architecture of the virtual worlds in Web 3.0, we can also develop a mixed reality-based cybernetic architecture to help the built environment adapt to virtual functions such as interactivity while retaining its relevance.

Image 2: Screenshot of a room scan using the Space Setup option in the Meta Quest 3 MR device.

Consumer-grade mixed reality devices are relatively new; hence, the applications designed and developed for them are limited in number and functionality. While they possess capabilities of context awareness that enable them to perceive and measure spatial attributes of a given physical space, the MR environments designed with them are modular and lean toward a 'one-size-fits-all' approach. This means that an MR experience can be played in any room once the device scans the room, producing a digital mesh of the floor, walls, and ceiling to overlay the virtual scene. While this modular design can be helpful in certain use cases, this design approach discounts the physical, geographical, and sociocultural context of the architecture in which it is situated. It suffers from 'placelessness,' what Edward Relph (1976) calls "the casual eradication of distinctive places and the making of standardized landscapes that result from an insensitivity to the significance of place" (Preface).

For centuries, architecture has been instrumental in crafting immersive spaces owing to its inherent qualities, methods, techniques, and concepts of place-making, which can now be drawn upon as we shape blended real-virtual spaces for a type of cybernetic architecture, Mixed Reality Architecture. This will not only help in crafting richer and better-integrated environments but also help in developing a Context-Specific Design approach that defies the place-lessness and mindless modularity of our post-modern world– a design approach that is currently absent.

In retail, a Concept or Brand Experience Store is an excellent architectural building typology to start exploring this idea. Such high-end retail spaces are designed to immerse the customer and provide plenty of opportunities for spatial media integration. Such retail spaces also pose an interesting problem of becoming - contextually dissociative, meaning a store could be in Japan or the United States and yet be identical copies with little or no regard to its immediate or larger context. This pattern is now moving into cybernetic architecture as we build massive shopping centers in the Metaverse like *Nikeland* (Sutcliffe, 2022). This concern, too, can be best addressed by formulating designs for MR retail stores that adopt a Context-Specific Design approach.

1.3 Motivation and my position in the research

The research examines 'How can we enhance architectural experience with Mixed Reality?' and 'How does this technology impact architectural design?'.

Trained as an architect, I perceive architecture, whether real or virtual, as an assemblage of material qualities, human agency, and design choices that form a co-dependent system subject to constant change.

While I consider myself a tinkerer and a dreamer, I wear different hats in this research: architect, researcher, developer, and UX designer.

The first realization for this project came from my undergraduate thesis in 2020. This architectural proposal was a metaphor for Mystery, set in an extreme salt desert landscape; here, concepts like wonder and curiosity were cast into surreal built forms to create enchanting spaces. While the project was successful on its own, it brought my attention to the limitations of architecture as a medium for creating interactive and immersive spaces when the material is only physical.

I also plan to develop this research into a creative practice. Since MR technology is relatively new, much remains to be explored, making it an opportunity for designers and architects to explore MR's use cases and push the architecture field to new frontiers.

1.4 Research Question

This research explores the following two-part question:

- How can we use architectural elements to design mixed reality environments that are context-specific?
- How can we use architectural design methods for designing such environments?

1.5 Goals and Objectives

- Conduct a comprehensive review and analysis of the following topics to position this research in these broader fields of study:
  - Applications of XR technologies in the field of architecture
  - Methods of architectural design
  - Architecture integrated with digital media.

  - Cybernetic architecture and projects in it
  - Use of digital media and XR in retail stores

- Learn the basics of XR development and create augmented reality apps for exploring relevant concepts.
- Study the developer's documentation for Meta Quest 3 and develop MR apps in Unity 3D for the device.
- Formulate a Context-Specific Design approach for the MR environment by employing architectural methods, concepts, and techniques in design.
- Design and develop a finished prototype that demonstrates using the Context Specific Design Approach.
- Evaluate and reflect on all the research findings.

1.6 Scope

The prototype designed and developed as the proof-of-concept for the proposed Context-Specific Design approach is limited to only one building typology, a retail store, to maintain focus and clarity while building an in-depth argument. However, the methods, concepts, and techniques can be applicable elsewhere.

The research question focuses on 'how' we can produce these desired goals and hence leans towards the design and development stage of the production process and does not diverge into user testing.

02. LITERATURE AND CONTEXTUAL REVIEW

This chapter takes a deep dive into this research's four main areas of interest: mixed reality, media architecture, cybernetic architecture, and experiential retail. The figure below illustrates how these areas are interrelated and connected to adjacent fields.

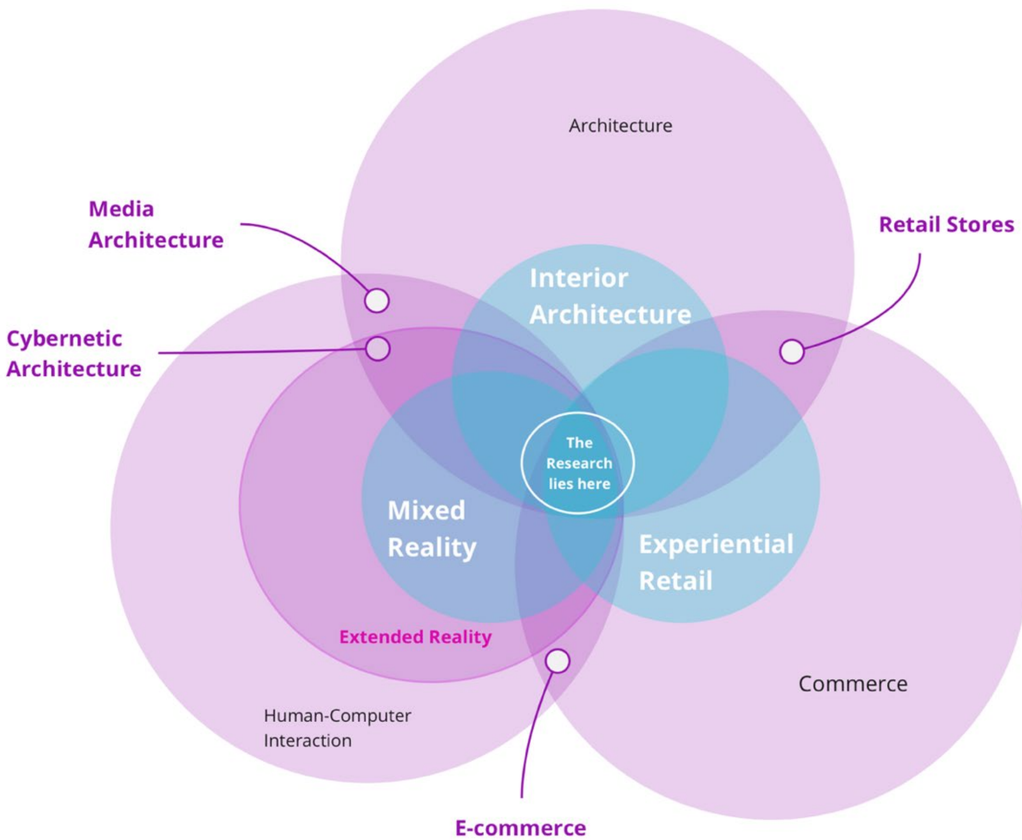


Figure 1: A Venn diagram showing how the research is situated in the larger fields of study. Own Work.

2.1 Mixed Reality

As different scientists, artists, engineers, and philosophers got involved over the years in the making of what we know today as immersive technologies or Extended Reality technologies, the terms Virtual Reality (VR) and Augmented Reality (AR) became widely accepted (Greengard, 2019). VR is the state of being perceptually immersed in a digitally modelled virtual environment, and AR is a type of immersion that virtually manipulates the natural environment. In 1994, Milgram et al. proposed an advanced conceptual framework called the Reality-Virtuality Continuum.

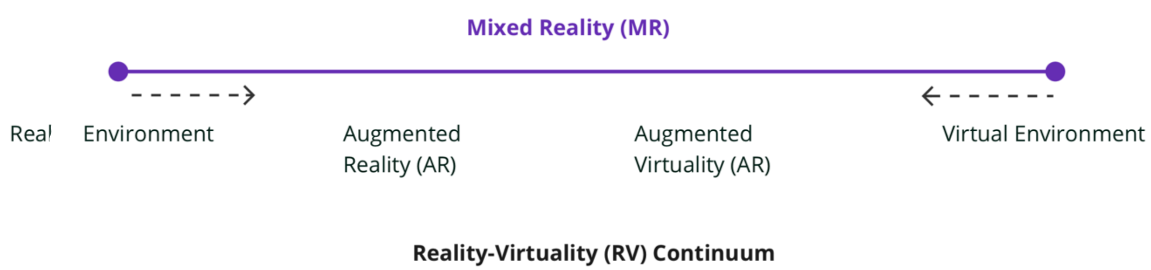


Figure 2: Show Mixed Reality in reference to the Reality-Virtuality Continuum.

Note. Adapted From "Augmented reality: a class of displays on the reality-virtuality continuum" , P. Milgram, H. Takemura, A. Utsumi and F. Kishino, 1994, Telemanipulator and Telepresence Technologies, SPIE Vol. 2351, p. 290, doi 10.1117/12.197321.

According to this model, the Real Environment and the Virtual Environment exist on the opposite ends of a continuum, with Augmented Reality and Augmented Virtuality placed between the two. Here, Mixed Reality (MR) becomes an all-encompassing term for all types of reality on the continuum. Augmented reality (AR) is a reality that leans toward the Real Environment and overlays virtual imagery on it. On the contrary, Augmented virtuality (AV) leans towards the Virtual Environment, as it takes real-world imagery to place it in the virtual environment (Milgram et al., 1994). While some distinguish these technologies based on the continuum, others have taken a different route- AR, VR, and MR are seen as distinct technologies under the umbrella term of Extended Reality (XR).

While the continuum helps put the nature of these 'realities' into perspective, this research adopts the latter framework of XR technology. It identifies MR as a distinct type of immersive technology independent of AR and VR. Here, MR is understood as a type of reality that enables us to create real-virtual blended environments where real-world objects have virtual computer-generated counterparts (Bekele, 2021).

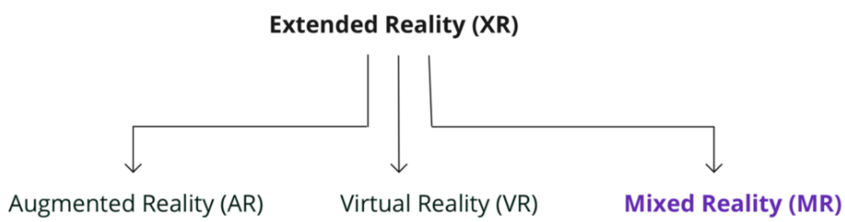
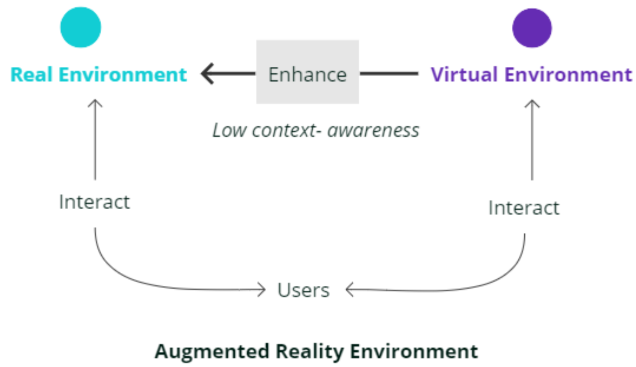


Figure 3: Depicts the mixed reality under the umbrella term of extended reality.

MR and AR may appear similar, but MR's certain capabilities clearly set it apart. MR requires specialized head-mounted devices with sensors for tracking, which allows for more complex interactions than AR. Another distinct MR feature crucial to this research is its context awareness. Bekele (2021), in his chapter of the book Virtual Heritage, explains this by drawing a comparison between AR and MR to identify "the contextual relationship between users, the real world, and the virtual environment" (p. 95). The illustration below, in reference to Bekele's diagrams (2021, p. 96 – p. 97), helps understand this better.



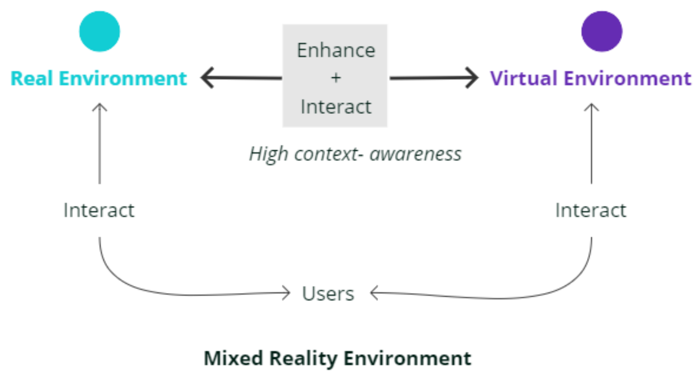


Figure 4: The figure make a comparison between AR and MR environment and shows the relationships between their many components.

Note. Adapted from Virtual Heritage: A Concise Guide (p. 96-97) by M. Bekele, 2021, Ubiquity Press.

2.1.1 *General applications of XR technologies*

The last decade has witnessed great advancement in user-friendly XR technologies and remarkable growth in its application across diverse fields. To contextualize XR, we expand and loosely categorize Schipper and Holmes's (2021) list below.

- High-end entertainment venues: These consist of VR parlours and event spaces such as VOID, which offer experiences in the form of VR games, VR and AR Interactive storytelling, and simulations, fully equipped with high-end VR headsets and haptic devices.

- Designed for Personal Head-Mounted Devices: These include video games, meditation apps, skill learning apps, and various types of VR tools that can be purchased or played by individuals who own HMDs right at home.
- Smartphone Applications are the most accessible, as smartphone technology is commonplace globally and across different economic groups. Such applications are usually made with AR technology for AR games like Pokémon Go, AR visualization tools for interior furniture and educational purposes, AR fitness coaching, AR measurements, AR Art, and AR shopping.
- High-stakes skills: VR is used to teach high-stakes skills in different professions, such as simulated airplane cockpits in pilot training programs and medical surgical procedures to train medical professionals. VR replaces standard training methods, reduces costs, and helps avoid life-threatening consequences.
- Cultural applications: While AR and VR has been in use inside Museums and other cultural destinations, MR is slowly gaining traction in animating otherwise static museum exhibits, historical storytelling, digital restoration, and archival of artifacts. Virtual travel experiences are also becoming common along with the introduction of XR at theme parks.
- Navigation and Instructions: AR overlays are taking over street navigation, wayfinding inside buildings, marketing materials for retail products, and the 'How-to' manuals for product assembly and maintenance.

2.1.2 XR technologies in Architecture: Inside the life cycle of a building.

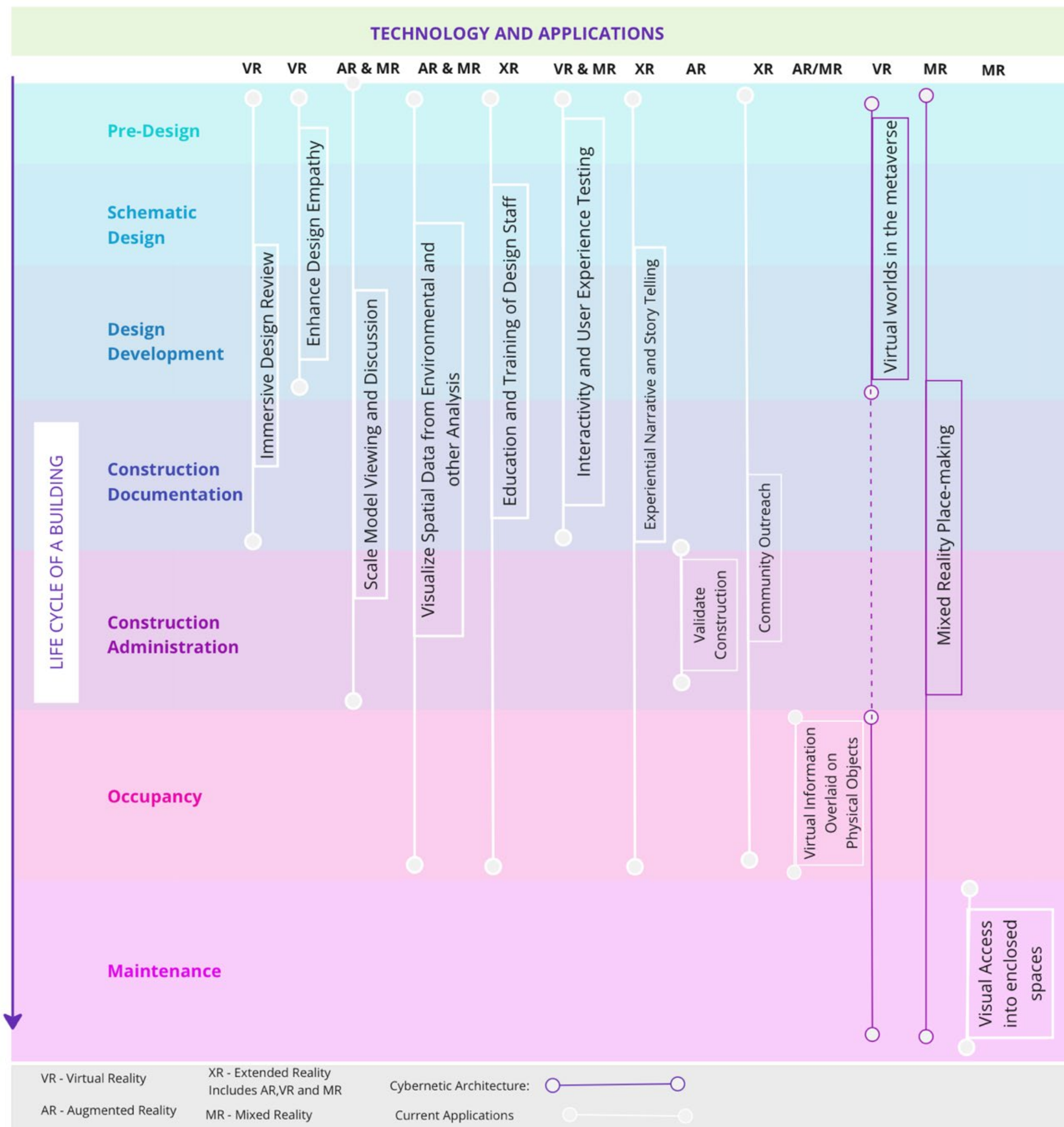


Figure 5: The figure shows applications of XR technologies at different stages in the lifecycle of a building. It also positions cybernetic architecture in relation to conventional architectural practice.

Note. Adapted by Schipper, D., & Holmes, B. (2021). How Architects are using Immersive Technology Today, and Projections for the Future. In Virtual Aesthetics in Architecture (pp. 43–49). Routledge.

XR technologies have been used in almost every stage of building construction, from pre-design to occupancy (Schipper & Holmes, 2021). The figure above illustrates how XR technologies are used as tools in the Building

Construction process. Virtual Reality technology is mainly used for immersive design reviews, and Augmented Reality tools aid in visualizing construction processes, drawings, and models. Commercially available, MR technology is relatively new. While it has been beneficial as a visualization tool in architectural applications, it should not be restricted as it promises far-reaching possibilities for creating blended architectural experiences. It has an unparalleled potential to become a medium for place-making.

2.1.3 Context-Awareness in MR

Both AR and MR use sensors to scan the real environment and overlay virtual content on it, as shown in Figure 5. While they are both context-aware, MR better suits the purpose of this research as it not only exhibits higher levels of immersion, interactivity, and embodiment, but the two-way dialogue between the real environment and the virtual environment also creates higher context awareness.

Context awareness in MR is the device's capability to sense, remember, and adapt to the physical environment of its users and comes as a product of its many different features:

- Passthrough: A passthrough is among the core features of MR. It uses the device's sensors and reconstructs the user's real-time view of their surroundings, similar to what they would see if they were to look at the room without wearing the headset (Use Passthrough on Meta Quest, n.d.). The passthrough can be manipulated for occlusion, creating virtual windows, aesthetics, and distortions of the real environment perceived through the device.
- Spatial Mapping: To create an MR scene, the device first performs spatial mapping to scan the user's room (the Real-World environment) and superimposes a digital mesh on it to create a Scene Model or a Digital Twin (DT). A scene model accurately aligns with the room's walls, ceiling, floor, and furniture and recognizes its basic components. The Scene Model then works as a point of reference to populate the MR environment with anchors and to position the user in the real-virtual space.

- Scene Anchors and Spatial Anchors: Virtual interactable objects are placed as Anchors in an MR Environment based on a coordinate system in an MR space. They are assigned unique IDs to help locate and differentiate them from other anchors (Spatial Anchors, 2023).
- Multimodal Interaction: One can interact in an MR environment through multiple modes. In addition to interacting with hand-held Controllers, hand pose detection, eye tracking, and voice commands can also be used. Different modes allow different types of engagement and embodied sensations.
- Multi-user experience: Multi-user experience is not used in this research but can be a valuable future addition for creating a shared MR experience. A multi-user MR experience called co-location occurs when users share the same physical location. In contrast, in a Remote Experience, users share the same virtuality but are in different physical locations (Shared experiences in mixed reality, 2022).

MR allows us to create a truly blended environment by making the physicality of the place an active agent in the experience. Bekele calls it "a fusion of both that neither the real nor the virtual world would have meaning without a contextual relationship and interaction with each other" (2021, p. 94). One of the early seminal papers that proposed a system for accurate real-time mapping of complex and arbitrary indoor scenes was *Kinectfusion: Real-time dense surface mapping and tracking* (2011) by Newcombe et al.

To understand the current approach better, we can do a close examination of a related work, First Encounters, a game by Meta, and then, from it, draw a basic framework for positioning the desired Context-specific design approach relative to the current modular approach to the design of MR environments.

2.1.4 Analyzing the Environment Design of MR game, First Encounters

Image 3: Screenshots from the mixed reality game, First Encounters (Meta, 2023). On the left – Virtual gun. On the Right- The Room becomes 'an enclosure'.

First Encounters is a Single-User, Room scale, Mixed-Reality Shooting Game by Meta (2023) that transforms the player's room into an extra-terrestrial play arena. In the game, the Meta Quest controllers transform into a virtual gun for shooting puffer aliens that invade the user's 'room'- a real-virtual room.

Below are some of the ways in the which the design of the game uses context awareness:

- Randomized spawn: Once the user completes the 'Space setup' for the room in which he/she wishes to play, the game automatically loads and places pre-defined game objects in the MR environment. Their spawning positions appear to be randomized.

Image 4: Screenshots of the mixed reality game, First Encounters (Meta, 2023). On the left – ‘holes’ in the . On the Right- The Room becomes ‘an enclosure’.

- Walls and ceiling as an enclosure: The game is played in full passthrough; the walls and ceiling begin to rupture on collision, and as the gun is fired, ‘holes’ form in the enclosure, i.e., the user’s room. As more holes are made, the alien landscape ‘outside the enclosure’ becomes visible. This creates an illusion of the real-world room being located on an alien planet.
- Real-Virtual world alignment: The alien landscape is aligned with the floor level, and the virtual sky appears ‘above’ the ceiling of the user’s room, effectively blending the real and the virtual.
- Occlusion and physics: Space puffins appear to be ‘crawling’ on the floor, and they are also occluded by objects in the Real-Environment furniture. The occlusion and physics make them seem ‘present’ among the real-world objects of the room. Physics is used to create an illusion of gravity and collisions, maintaining the realism of the blended environment.

2.2 Context: From Architecture to MR

This research seeks to design an MR environment whose virtual half is designed and developed for a specific context. 'However, the term 'context' is quite broad and its meaning may vary depending on the situation. Therefore, it's necessary to establish the various interpretations of the term. To achieve this, we'll begin by examining architecture and then move on to MR to develop a design approach that caters to the specific context.

2.2.1 Context in Architecture

In architecture, the term 'context' refers to a variety of tangible and intangible factors, such as the physical location, geography, climate, socio-culture, economics, and politics. When we use the word 'context', we are referring to distinct and interconnected aspects of a place. For instance, the climatic context of a building highlights all the climatic characteristics and trends of the location, or a sum of multiple contexts. In architecture, 'context' can also refer to something subjective and case specific. For example, if we design a community center for a specific tribe, their unique habits and routines become 'an important part of the context' for which the building is designed. Context can also be distinguished based on distance from the building; the *immediate context,* for example, refers to the physical characteristics of a site and its surroundings; meanwhile, when we study context at a neighborhood level, the context here may refer to the influence of existing buildings, roads etc. on the building.

'Context' is a relational concept, meaning it can only exist between two or more entities; for example, a neighborhood street can provide context to a building, or similarly, a building's features can be the context for the street's character. Its use in architecture also serves the same purpose. While architects have several different nuanced interpretations of the term, they all use 'context' to define, acknowledge or respond to the tangible and intangible aspects of the built environment.

Contextualism in architecture has existed for a long time. However, it became a recognized term and practice in the field as a response to modernist ideologies, which were interested in an international style of design that valued personal style and abstraction in its design and was independent of its context. Naeem Abrar defines *contextualism* as "the architecture that provides a solution or responses to the main characteristics of the area and the available site." (2021, p. 297). Contextualism is especially emphasized when architecture deals with sites that are historically or culturally significant, as it helps make architectural designs that are contextually sensitive. Contextualism in architecture has existed for a long time. However, it became a recognized term and practice in the field as a response to modernist ideologies, which were interested in an international style of design that valued personal style and abstraction in its design and was independent of its context. Naeem Abrar defines contextualism or contextual architecture also as "the architecture that provides a solution or responses to the main characteristics of the area and the available site." (2021, p. 297). Contextualism is especially emphasized when architecture deals with sites that are historically or culturally significant, as it helps make architectural designs that are contextually sensitive.

2.2.2 Contextual design in in this Research

In this research, contextual design is used to create richer and more immersive blended MR environments that use architectural elements as active agents in design. The use of contextual design in this project can be easily understood by building on Abrar's (2021) explanation of the term. Hence, the 'contextual approach' or 'contextual design' in this research is:

a) Context-dependent - When a contextual approach is adopted, the 'object' of design becomes context-dependent.

b) Sum is greater than the parts- Contextual design "strengthens the relationship with its specific site or its broader physical, or visual environment to create a whole that is greater than the sum of its parts" (Abrar, 2021,p. 297).

c) Planning principle—The perception of ‘context’ in architectural design or the design of MR environments determines fundamental features such as style, texture, material selection, orientation, proportions, and layout, making contextual design a planning principle (Vukmirovic et al., 2015).

2.2.3 Limitations of Context-Awareness in MR

The previous section of this chapter explains the many features of context awareness. It defines it as the 'device's capability to sense, remember and adapt to the physical environment of its users.'

This section goes deeper, critically examining it further to ask: How does an MR device perceive a built environment? How truly 'context-aware' is it?

In their paper "Context-Aware Mixed Reality: A Framework for Ubiquitous Interaction," Long Chen et al. describe MR's context awareness as "geometry-aware MR systems" (Long Chen et al., 2018, p. 2). This claim implies that MR devices solely rely on the detected mesh geometry for their 'context-awareness,' meaning that this 'context-awareness' does not factor in all the tangible and intangible attributes of the built environment.

In this project, we use the Meta Quest 3 for MR development. Despite being a high-end device and the best standalone MR headset in 2024, it allows for a limited semantic classification of the elements in the physical space. This vital function requires manual setup.

Current research and development in this area will improve detection, semantic classification, and inclusion of ML models that help distinguish physical attributes such as collision based on physical materials. Enhancement of context awareness will help create a more 'realistic' MR experience, making the blended real-virtual experience as seamless as possible.

However, there are two problems;

- First, MR's context awareness capability is limited to its being 'geometry-aware,' meaning that all other physical and non-physical responses to the context in MR have to be manually designed and developed In detail by somebody.
- Second, even if MR technology has greatly advanced in creating seamless real-virtual experiences, we will still require somebody to design the environment using such an advanced context-aware system.

In both cases, MR environment designers require frameworks and methods for using MR's context-aware capability to create context-specific environments.

2.2.4 Introducing Context-Specific design for MR environments.

Context-specific design is an approach in which the virtual components are specifically designed to complement the contextual features of the built environment for which the MR experience is designed. This project's contextual features mainly include physical features- furniture, walls, ceiling, windows, floor, and materials, and conceptual features drawn from the fictional scenario. However, contextual features can also come from climatic, socio-cultural, and historical contexts.

	Current Approach to Mixed Reality **Modular Design**	**Proposed Approach to Mixed Reality** **Context- Specific**
Characterstics	• Uses context awareness. Can be played in any room or physical setting. • Modular design can be adapted to any physical setting with the same parameters. Ex: Meta's *First Encounters*	• Uses context awareness. • Can be played in designates spaces and is mapped to specific physical setting.
Modularity Makes a design easy to adapt to any room.	High	Low to Medium
Materiality	Low to Medium	High
Overall consistency in visual aesthetic	Low	Medium to High
Effective Physical-digital Interfaces	Low	Medium to High
Typical Setup time	Low	High

Figure 6: Shows the characteristics of proposed context-specific design in comparison to the current approach.

For a broad understanding, we can position the proposed Context-Specific design in relation to the currently used general design approach, which can be described as 'modular' because of its one-size-fits-all approach. Such an MR experience could be played in 'any room,' irrespective of the real-world context. In the diagram above, we use the characteristics of the current 'modular approach' to project the desired characteristics of the proposed approach.

In chapters 4 and 5, we explore and examine context-specific design in more detail as we design and develop prototypes.

2.3 Media Architecture: How is media shaping buildings and cities?

When we speculate on the design of a real-virtual, blended form of architecture, we seek to craft the built environment with digital media. Before venturing into such place-making, we must understand the relationship between media and architecture. This section draws on the historical relationship between media and architecture and dives into the field of Media Architecture.

2.3.1 The evolving history of media & architecture

Media Architecture refers to integrating digital media into architectural buildings by creating digital facades, projection mapping, urban screens, and temporary media installations (Chan, 2019). Although Media Architecture has become a recognized field more recently, the relationship between Architecture and Media is as old as our first known homes.

Media integration in architecture became sophisticated as time progressed– sculptures, murals, and mosaics came to be designed with themes and narratives to work in harmony across large palaces and building complexes. Building techniques and material science advancements enabled media integration into built spaces' very structure and core functions. South Asian temples, for example, display extensive wealth and labor invested in intricately carving religious narratives in stone from the floor to the ceiling, both on the interiors and exteriors, substantiating that the demand for media often surpassed the structural functions of the buildings.

In the heat of the Industrial Revolution and between the World Wars, Modernism stripped off media of the buildings. The notion of "house is a machine for living in" (Corbusier, 1920) and International Style sent a wave of concrete look-alikes worldwide. This period also witnessed the birth of modern mass media, photography, and television. The advent of digital computation systems forever changed how we made, shared, and retrieved media. Computers advanced, shrunk in size, and gave birth to the internet; this pushed digital media not only onto desktops, televisions, and cellular phones but also building facades, highway billboards, neighborhood kiosks, and town square displays.

2.3.2 Digital Media as a Building Material.

Digital Media permeates the fabric of 21st-century cities, inside the skin and bones of Architecture. As our cities became increasingly digitized and data-driven, built structures transformed into media interfaces, and massive digital facades animated the skyline. Digital media integration became no longer an afterthought but a primary consideration in the construction process.

a) The Digital Bricks: This project by Neils Wouters and Susie Anderson from the University of Melbourne was created for the science gallery at Melbourne Connect and was the result of a design research (Wouters & Anderson, 2021).

Image 5: Front view of the Digital Brick Wall.

Image 6: Close-up view of the Digital brick.

Note. Image 3 and Image 4 are by Wouters, N., & Anderson, S. (2021, April 15). If these walls could talk. Pursuit; The University of Melbourne. https://pursuit.unimelb.edu.au/articles/if-these-walls-could-talk. Licensed under Creative Commons Attribution-No Derivatives 3.0 Australia (CC BY-ND 3.0 AU)

The wall is an assembly of electronic sensors, computer graphics cards, bond clay, and glass bricks. This digitized wall seamlessly merges with the surrounding brick wall. The project was designed to be a place for local histories and storytelling, where the 'building can interact with people' through touch and tap.

b) MUURmelaar is a sound-based media façade that dynamically responds to passers-by's movements. The project was created in collaboration by DMOA and the research group Research[x]Design (RxD) at KU Leuven. In this project, they explore the 'living façade' idea and use digitally produced sound as material. The soundscapes are created as people unknowingly interact with the building's surroundings.

Image 7: A visualisation showing human movement trigger sound response from the building.
Note. Photo Visualisation by (MUURmelaar: An interactive sound-based media facade with architectural value. (n.d.). Research[x]Design. Retrieved March 15, 2024, from https://rxd.architectuur.kuleuven.be/projects/muurmelaar/

Buildings, once used to remain relatively unchanged once constructed but with modern technology they are becoming dynamic and responsive, massive digital canvases for watching digital content. Owing to this, the temporal aspects of the built environment have been expanding to accommodate new functions. Buildings have also become extensions of digitally networked systems connected through Interfaces, projections, lighting, sensors, audio systems, etc. The emerging practice of Media Architecture is taking shape, and Mixed Reality technology is one of the emerging technologies that has great potential that is yet to be fully explored in the practice.

2.4 Cybernetic Architecture

The field of cybernetics has been around for a few decades and has permeated almost all fields. The term has gained several interpretations in different fields of study. However, its root meaning is derived from the Greek “Kybernan,” meaning “to steer” (Definition of Cybernetics, n.d.), and deals with the science of “how different systems use information, construct models, and exercise control actions to steer themselves towards their goals” (Zhang, 2023, p. 39).

The goal of this research alludes to the third goal of one of the three current general research goals observed and listed by Zihao Zhang (2023) in the field of cybernetics of “developing better cyber-physical systems to devise control policies and control actions” (p.37). The interest lies in designing spatial interfaces for a system, specifically a Mixed Reality system, in which control and communication occur across ‘the Real Environment,’ ‘the virtual environment,’ and ‘the observer.’

Hayles’s (1999) seminal work, How We Became Posthuman, breaks down the evolution of the field of cybernetics into what she terms “The three waves of cybernetics” (pp.1-24), explaining how each wave has taken a different course of development. The concepts from the second and third waves of cybernetics interest this research, where humans are put into the system and allowed to extend human control via machine intelligence (Zhang, 2023).

Cybernetic Architecture in this research can be best understood by ZH VR Group’s Manifesto. ZH VR Group is part of the pioneering Zaha Hadid Architects architecture and design firm specializing in the multifaceted digitization of architectural processes and production. ZH VR group is leading Virtual reality-based architectural creations by creating VR design tools, VR platforms and applications, and research in cybernetic aesthetics in architecture (About, n.d.). Their Cybernetic Architecture Manifesto (Kinzler et al., 2022) defines *cybernetic architecture* as “the design and creation of spatial constructs that extend into cyberspace”(para. 1). Their approach positions VR technology as an apparatus for a type of immersive architecture, comprising of blended reality spaces that lie on the continuum between the physical reality (Real environment) and cyberspace (Virtual environment). Moreover, their strategies and solutions are rooted in embodied human experiences.

Therefore, Cybernetic architecture can be understood as the design and creation of cyberphysical architectural systems, processes, and places using extended reality technologies that lie on the Reality-Virtuality continuum.

2.4.1 Cybernetic architecture in practice

ZH VR Group's *Verse 1.0*, made in collaboration with Meta Gravity, is a virtual world built for the metaverse and is an example of Cybernetic architecture. The human-centric project boasts residences, stadiums, concert halls, galleries, and even special transportation designed with whole cities inside the virtual world. Multi-presence is central to this project. Multi-presence VR are VR environments that are built to enable, accommodate, and cater to the simultaneous presence of a typically large number of users (*Verse1.0 —*, n.d.).

Image 8: : Bird eye view of Verse 1.0 by ZH VR. Note. Verse1.0 —. (n.d.). Zaha Hadid Virtual Reality Group. Retrieved March 11, 2024, from https://www.zhvrgroup.com/verse1

Bjarke Ingles Group, also known as BIG, is a Danish Architectural studio that, in 2022, built its first metaverse building, a virtual office space called Viceverse for the Vice Media Group. This Virtual Place is an experimental place for the company's employees to conduct business and experiment with NFTs(Non-fungible Tokens) and Decentralised Autonomous organizations (Finney, 2022).

Since most architects working in virtuality are designing and building for Metaverse or Web 3.0 platforms, it can be misinterpreted that cybernetic architecture is limited to Virtual Reality or Metaverse. Hence, it is essential to establish that cybernetic architecture, by its nature of cybernetics, encompasses a much broader range of 'cyberphysical architectural systems, processes, and places' that use immersive XR.

Image 9: Photograph showing the Angelus Novus Vault. (Aouf, 2023)
Note. Aouf, R. S. (2023, June 1). SOM and Princeton University use AR to construct self-balancing arch in Venice. Dezeen. https://www.dezeen.com/2023/06/01/som-princeton-university-self-balancing-arch-venice-architecture-biennale/

An example of a cybernetic architectural construction is a project in which SOM, an architectural firm, and Princeton University collaborated to design and build the Angelus Novus Vault, a double curved structure using what they termed as a “mixed-reality construction approach” (Aouf, 2023, para. 3).

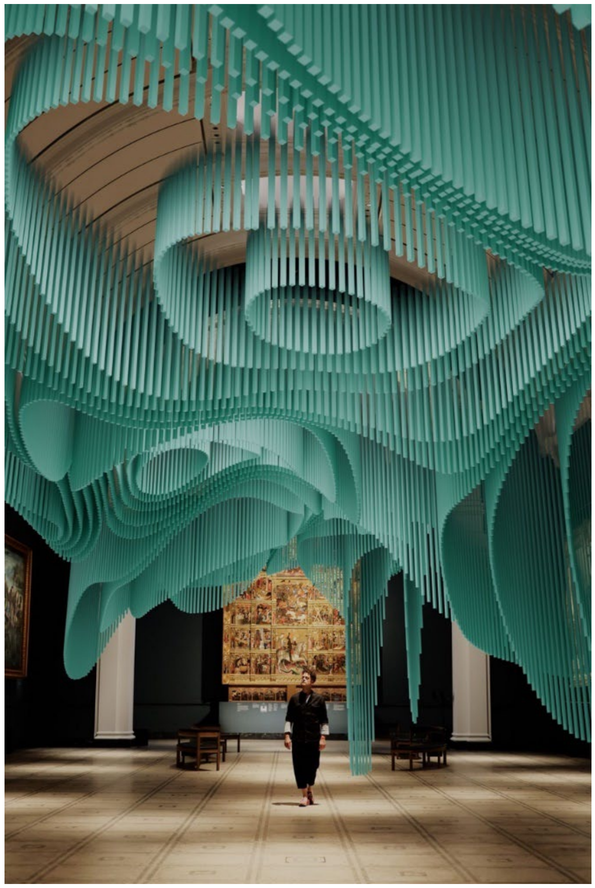


Image 10:Medusa a mixed reality installation by Fujimoto and Tin Drum.

Note. Finney, A. (2021, September 19). Sou Fujimoto creates undulating virtual installation in London. Dezeen.

https://www.dezeen.com/2021/09/19/medusa-sou-fujimoto-virtual-reality-installation-london-design-festival/

Another example of room-scale cybernetic architecture is an installation by the Japanese architect Sou Fujimoto in collaboration with Tin Drum a mixed reality studio, called the Medusa. This experience allows 50 guests wearing mixed-reality glasses to experience a dynamic structure, an “experimental architectural form” that responds to the movement of the guests (Finney, 2021, para. 3).

In another case, a mixed reality museum experience was made for the Museum of Cairo, where physical museum glass displays were virtually augmented with text and 3D graphics, interactive games became part of the exhibits, and museum halls were augmented with virtual models, all experienced using the Microsoft HoloLens (Hole, 2021).

2.4.2 Cybernetic architecture in this research

ZH VR's Manifesto accurately claims cybernetic architecture as "not a style" and "not a revolution" (Kinzler et al., 2022, para 3-4). It describes cyberspace as akin to a newborn world(s) that will grow and evolve to produce new aesthetic considerations as people and cultures engage with it (Kinzler et al., 2022).

While ZH VR's work mainly discusses developing cybernetic architecture for VR technologies, the fundamentals remain largely the same. Experiments in the architecture of cyberspace and cyberphysical systems are said to give rise to different types of cybernetic architectures.

2.5 Experiential Retail

Experience economy was a term coined by B Joseph Pine II and James H Gilmore, referring to a major shift in consumer behavior from placing value only on goods and services to placing value on experiences (Joseph & Gilmore, 2011).

Recognizing this changed how retailers used store space in an establishment. Big box retailers and others whose business model sustains economies of scale prioritize storage and sales over experiential values when designing the store layout. Brands whose business relies on factors like brand image and perceived value design their stores for customer experience. Instead of maximizing storage capacity and looking at them primarily as product distribution points, such stores approach them as experiential media channels.

In his book Reengineering Retail, Stephen Doughlas (2017) explains how retail stores are deeply intertwined with media. He puts forth two concepts, both of which hold true; 'media is the store' and 'the store is media.'

With experiential retail on the rise, the retail sector is a welcoming space for experimental design concepts, and the retail establishments aren't shying away from funding these projects. Hence, this rather capitalistic landscape, in a way, has become a lucrative space for innovation in interior design. Interior stores are also imbued with different types of media that urge engagement and exploration, unlike the typical interior of a house or an office space. This is due to the user group and their specific intention and mindset with which they inhabit these different spaces.

2.5.1 Media is the Store. The Store is Media.

As e-commerce continues to dominate the market, it is apparent that Andreesen's statement is largely true. However, the popular adoption of concepts like omni-channel is an indicator that the retail typology is morphing to fit into today's growing digital landscape.

Since then, almost all types of retailers, including the ones with physical stores, have had to adapt to the wave of e-commerce. One commonly adopted strategy by physical retailers wishing to expand into the digital market is called Omni-channel retailing. It is a retailing strategy that involves engaging customers with a brand by integrating both physical and digital touchpoints such as websites, different social media platforms, mobile applications & physical stores (n.d.).

Similar to the ancient Greek and Persian marketplaces, where although trade was the primary activity, the social sphere was closely intertwined with these places and could not be separated as it was what brought people there again and again and also kept them there longer. Today, almost all the digital platforms that had started off as only social media do not remain as such, as they all have naturally transitioned, extending into commerce. Across digital platforms, ' content' is the umbrella term for different types of media we consume, and it is the driving force of most engagement on these platforms. Businesses use content-commerce integration to drive their sales.

Communication is the fundamental function of all media. In architecture, we realise that the physical form of the built space and the media that inhabits it come together to create compelling experiences.

In the evolving landscape of retail, the role of offline brick-and-mortar stores is undergoing a transformation that goes beyond traditional retailing. These physical stores are becoming more than just places to make purchases; they are becoming immersive media platforms. This transformation is driven by the understanding that, in today's marketplace, consumer relationships are as essential as the products themselves.

2.5.2 XR in Retail

All cybernetic environments, irrespective of their immersivity, such as the World Wide Web, reflect the values of the society it mirrors. Hence, the cybernetic architecture of an increasingly capitalist world can be expected to persist as it is or heighten in magnitude. This research chooses to experiment with one architectural typology that sits in this landscape, best known for showcasing experiential qualities brought by architectural design and media integration: retail stores. Another indicator that points towards the importance of exploring this building typology is that it’s one of the first building typologies that is being designed and built for the metaverse at a massive scale.

Retail stores have been becoming increasingly contextually dissociative by design, and as we copy the building typology into the Metaverse or other web 3.0 platforms that are almost completely isolated from the real environment, we risk disseminating mixed reality in retail store architecture.

It's clear that mixed reality technologies could prove to be even more promising than augmented reality for in-store retail experiences. As mixed reality moves into this massive arena of retail, this question whether the it will heighten contextual dissonance of retail stores or steering away from it and move towards context-specificity.

2.5.3 Related Work: Nike's AR Integration

Nike has been actively exploring the use of AR and MR and other innovative technologies to enhance the customer experience in its retail stores worldwide.

- *Nike Fit:* An AR Product Trial: This is an AR feature built into the Nike App that targets one crucial point on their customer's journey; finding the right shoe size. The app uses a smartphone's camera to enable computer vision, scientific data, artificial intelligence, and recommendation algorithms to measure customers' feet and recommend the best-fitting shoe size (Alvarez, 2019). This not only helps reduce the likelihood of returns but also aims to address the statistics that claim that 60% of people wear the wrong size shoes (Alvarez, 2019). Nike claims that the AR app is able to get the size right to millimeters in accuracy and save the information in the app tied to the customer profile. The size can then can be used automatically to filter out best fits while shopping online or can also be used for in-store purchases at physical locations. The AR feature is promised to be useful, especially for parents who struggle to get the right size of shoes for their kids, as the kids' shoe sizes change drastically and frequently as they grow older (Alvarez, 2019).
- *Swoosh High* by *Nike x Snapchat*: This is an AR Kiosk. Snapchat's AR Mirror is an AR feature within the Snapchat app, which allows virtual try-ons and experience products of different brands. In this campaign, Nike partnered with Snapchat to focus on back-to-school items such as bags, sneakers, and other accessories. Besides virtual product trials, customers could also play small interactive games and win discount coupons redeemable in the stores. Instead of launching it online for mobile-based interaction, they were installed as in-store interactive AR kiosks inside Nike's physical stores (*Nike AR partnership*, n.d.).
- *RTFKT x Nike* AR *Genesis* Hoodie: Nike is extending its digital footprint in Web3 and has bought RTFKT, a design studio that produces digital fashion and other collectibles. Their AR Genesis hoodies is issued as an NFT and can be worn by user's virtual avatars as well as the real-life user. The

hoodie is inserted with an NFC(near-field communication) chip, enabling wireless communication between the real-world hoodie and the digital hoodie. The owners of the hoodie can also add other virtual assets on it, like virtual wings (Waldman, 2022).

AR Integration	In-Collaboration	Type	Hardware	Function	Purpose	Use Location
Nike Fit	-	AR Feature	Mobile Based App	Detect Shoe size	Fix and enhance a checkpoint for purchase.	Online or In-store
Swoosh High Campaign	Nike x Snapchat	AR Installation	Kiosk	Virtual product try-ons, Interactive games, issue discount coupons	Back-to-school seasonal marketing	In-store
AR Genesis Hoodie	RTFKT x Nike	AR Phygital Product + Virtual Wear NFT	Mobile Based and Web Based	Digital Fashion product	A product launch for Web3	Online

Figure 7: Table compares different AR Integrations by Nike

03. RESEARCH METHODS & METHODOLOGY

MR technology is still emerging, meaning it has not been in the world long enough for its applications and impact on the world to be fully realized. This also means that there are no standard methods and methodologies for designing and developing MR environments, as new research in the field emerge the technology continues to evolve.

The research question asks a two-part question as mentioned in Chapter 1. First, 'How can we use architectural elements to design mixed reality environments that are context-specific?' and second 'How can we use architectural design methods for designing such environments?'

First part— In the previous chapter, we discussed how Context-specific design can be employed as a design approach for MR. To further develop this approach, we established relevant research methodologies. For this purpose, we turned to Human-Computer Interaction (HCI) and adopted the research through design methodology. This methodology is commonly used in the field and is particularly suitable for exploring human interaction aspects with mixed reality technology. In addition the rapid prototyping was also adopted from this methodology.

As the research aims to design real-virtual environments for the future of the built environment, it employs the Speculative Design methodology for futures thinking. Design research endeavours such as this one rely on drawing fictional scenarios that are tied to the current trajectory to design for. Speculative Design methodology helps to better understand how to draw and design for plausible futures - a commonly used methodology for foresight and strategy development. The method of scenario building adopted in this research is based on this methodology.

Second Part— To examine the role of architectural design methods in creating context-specific MR environments, certain architectural design methods are used and then assessed. These methods are not meant to replace the commonly used methods in XR development but supplement them.

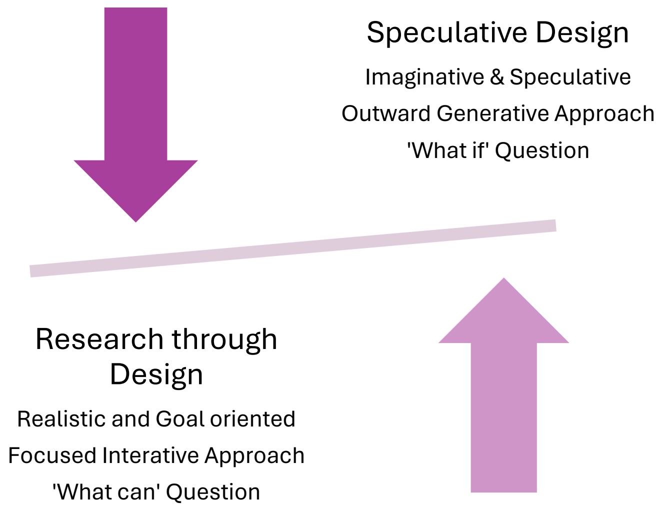


Figure 8: The balancing forces of the two methodologies as used in the research.

3.1 Methodologies

3.1.1 Research through Design for making ideas tangible.

Research through Design (RtD) is a methodology commonly used in HCI research where an inquiry is translated into a making process to gain insights. This is typically done by understanding the current state of an 'object' and then working towards a desired state (Zimmerman & Forlizzi, 2014). Here, while the direction toward the desired state is linear, the resultant path towards it is inherently iterative. Due to its iterative nature, the design constantly informs itself and brings attention to its opportunities and shortcomings. Hence, the design process becomes the research process.

RtD is an inward-focused approach rooted in Research through Creation. It focuses on the practical-making side of the research. Therefore, all the methods used following the methodology produce tangible ideas. This also helps keep the project grounded in what is possible with the currently available technology and knowledge.

Godin and Zahedi, referencing Seymour Papert's theory of Constructionism, say, "The advantage of researching through construction " is that it "sets the learner in a dialog with its environment and with the construction" (Godin & Zahedi, 2014, How do We Learn in RtD). Drawing from this idea, they propose that in RtD the researcher learns "about the object of their inquiry through the constant evolution of the artefact". Hence, In this research the "artefact" is the imagined MR environment, and the "object of inquiry" is its design and development.

When using RtD to develop MR prototypes, the researcher commonly performs recursive testing at intervals to make informed changes. Since the design and development process is crucial, it is often documented through notes, scripts, pictures, recordings, sketches, etc. This enables the researcher to trace the steps taken to evolve the artefact, providing insights for the inquiry. The documentation can also assist other researchers, designers, and developers with other projects. An intrinsic part of the methodology is enabling the research community to engage with both the product and the process critically.

3.1.2 Speculative design for a journey towards a preferable future

Speculative design is a practice rooted in Future studies that, contrary to traditional design thinking methodologies that deal with challenges of the present, involves future challenges. It dwells on the 'what if' to project possible futures, an approach that's especially useful when working with emerging technologies like MR. Typically, speculative design is used in identifying trends and evaluating future implications from a critical viewpoint, keeping sociological, ideological, and philosophical lenses in focus. However, this research uses the methodology as an enabler in the creation of the Context-specific design approach for MR that lies in the plausible near future.

The Futures cone has undergone several revisions over the decades as different futurists have added and removed classes that define the cone's time frame. Below is an illustration adapted from Joseph Voros's (2017) Futures cone to position this research.

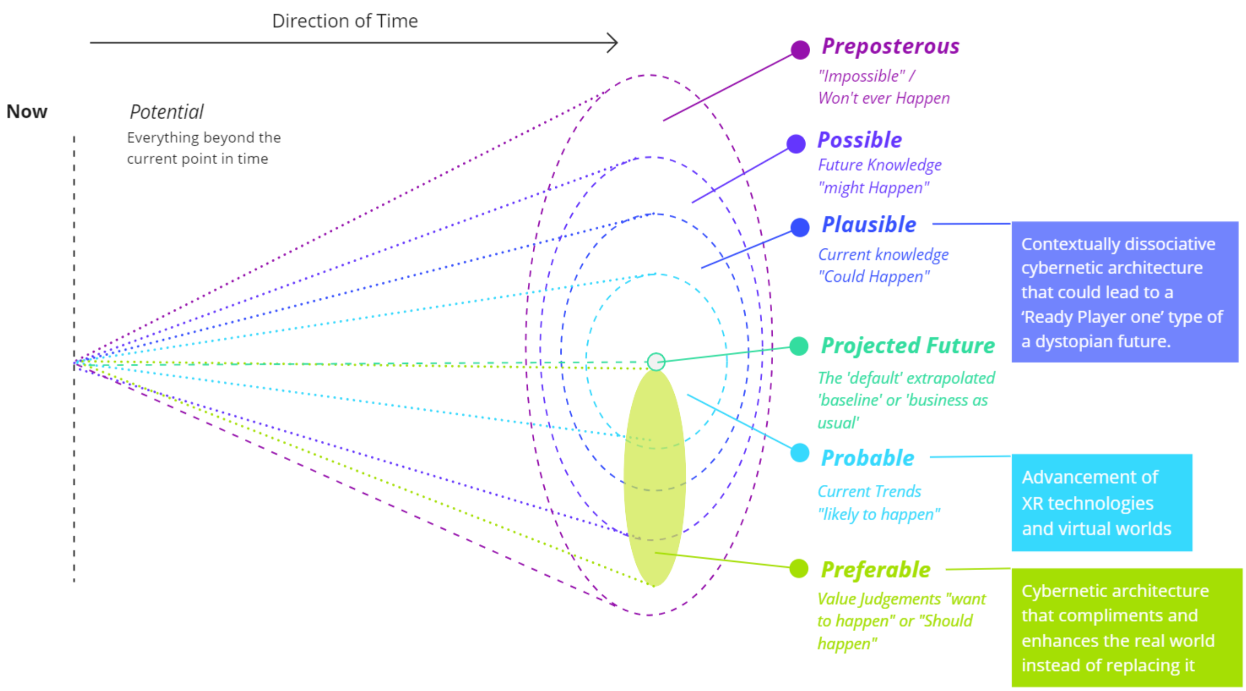


Figure 9: The Futures cone shows how the goal of the research is situated in relation to the future of XR and the built environment.

Note: The illustration is adapted from Joseph Voros's 2017 Futures Cone.

In the futures cone, the classes important to the discussion are the Plausible, the Preferable and the Projected Future.

- The Plausible future: It refers to the future that 'could happen' inferred based on current trends and knowledge. Here, the plausible future is where people use cyberspace to escape the real world. This is evident in how virtual rooms are replacing physical spaces and how people spend long hours in cyberspace. An example of such a dystopian future is Ready Player One, previously discussed in Chapter 1.

- The Probable Future: This refers to the future that is likely to happen if things continue as they are. Currently, we see rapid advancement in XR technologies, so it can be said that the technologies will continue to get more sophisticated. For example, the platforms of web 3.0 have been growing and are likely to continue growing.
- The preferable future: This class refers to the future that we 'want to happen', which can overlap with any other class. In this research, the preferable future is where we continue to develop XR technologies and cybernetic environments that complement, enhance, and add value to the real world. In the cybernetic future, virtual worlds will coexist in harmony with the real world.

These futures are projections from our current world and, hence, not fixed. This research aims to replace the plausible future with a preferable one. To do this, we first need to 'imagine' the preferred scenario. This is where the method of scenario building comes in.

3.2 Architectural Design methods

These are formal design methods from the field of architecture, both the traditional methods that have been used for centuries and the contemporary methods that are a result of the field adapting to new technologies.

3.2.1 Architectural Drawing as a method:

In this research, drawing as a method and technique flows into almost all stages of thinking and making. Different types of architectural drawings, like schematic drawings, conceptual drawings, floor plans and isometric drawings, serve different functions in terms of communication and relation to where they are used in the process. Drawing as a method in architecture not only corresponds to 'the drawing' as an object but also to the act of drawing as a process of analysing existing ideas and synthesizing new ones.

Both architecture and MR deal with spatial design experiences. Hence, using architectural drawings only seems like a natural addition to the process of MR development. The purpose of using architectural drawings in designing MR environments is not to replace the commonly used methods from UX design but to supplement them. MR, unlike VR or the design of virtual interfaces like websites and mobile apps, coexists with the built space in a physical setting; there is no 'blank canvas' to begin with. Moreover, this research prioritizes the elements of an architectural space, making the use of architectural drawings in the design process of MR more appropriate.

The following architectural drawings serve different functions in the design process of the MR environment:

a) Schematic Drawings are used in visualizing abstract concepts, the relationships between different components, breakdown processes and defining different parts that come together to form assemblies.
b) Conceptual Drawings help brainstorm possible designs quickly without the need to add secondary details. They are bite-sized drawings that capture the essence of the 'concept' and can be developed further for more detail.
c) Annotated Drawings could be 2D or 3D drawings, such as annotated floor plans and annotated 3D sketches, that give information that cannot be drawn, such as digital interactions, animations, etc., that are common features of MR environments.
d) Layer drawings or drawings of exploded views help show how different parts come together in an assembly. In MR, they can also help show how virtual and real geometries come together in an environment.

3.2.2 Digital 3D modelling and Rendering, a method

This research uses rendered 3D models in the early explorations and the principal prototype. An architectural 3D model of the final exhibition setup helps envision the designed scenario's physical elements. This is crucial to the MR environment's design, as the experience's virtual layers are tailored to this specific physical setting.

Digital 3D models are usually used in conventional architectural design practice when certain fundamental design aspects have been finalized. 3D modelling in fields like parametric design and digital fabrication also becomes part of design's iterative process. 3D architectural models are useful in visualizing attributes of a physical place that can be better understood in 3 dimensions: light, colour, texture, volume, etc. 3D models are especially instrumental in communicating designs that have complex, difficult-to-read drawings.

3.3 Methods: Scenario Building and Prototyping

3.3.1 Prototyping

Prototyping is commonly used in design and technology due to its versatile nature. This project is the culmination of multiple prototypes and types of prototypes. Hence, instead of categorizing them into general types, such as low-fidelity and high-fidelity prototypes, it makes more sense to classify them based on how they contribute to this research.

The making in this research is structured around the prototypes. There are essentially two types of prototypes used and they as follow:

a) Proof of Concept prototypes (PoC)—The function of a PoC is to provide evidence to support a concept. They are not necessarily ‘finished products’ and help validate or invalidate a proposed idea. In Chapter 5, Early Explorations, two such prototypes are made using AR, and both help validate different concepts. While they are both Hi-fi prototypes, they are less resource-intensive and pose a relatively low barrier to entry, making AR suitable for a PoC.

b) Principal Prototype—This final prototype comes after the scenario building and is used as a base for iteratively developing the functional prototype. It is made up of different components, each of which exhibits a different design functionality. This is a High-Fidelity prototype built using MR. 3.2.2 Scenario Building.

3.3.2 Scenario Building

The Scenario Building method corresponds to speculative design methodology where, as mentioned before the research tries to turn the preferred future into the plausible one.

Scenario planning is a method commonly used in the class of plausible design, where one is concerned with exploration rather than prediction. In this method, multiple plausible scenarios are fleshed out, and strategies are developed for each one of them. However, in this research, I'm focusing on Scenario Building, where I take the preferred scenario and build an artefact for it. In this case the artefact is an imagined environment, the principal prototype. This artefact from the preferred future one created makes the preferred 'more' plausible. The artefact can also potentially give rise to multiple such artefacts from this preferred future.

a) Architectural drawings and 3D model prototypes- While architectural drawings and 3D models are methods in themselves, they are also used as techniques to support building one scenario or brainstorming multiple scenarios.

b) Fictional brief- The artefact to design is part of the Preferable future, hence it is important to first establish a specific context for the artefact. The context is established using a fictional design brief.

04. EARLY EXPLORATIONS

The early explorations in this project began with the need to build and test simple XR applications that used both the Real and the Virtual environments. An assessment of XR technologies (Figure 10) was carried out to understand the advantages and disadvantages of the technology, which would help in deciding the next steps. The early explorations in this project began with the need to build and test simple XR applications that used both the Real and the Virtual environments.

FEATURE	VIRTUAL REALITY (VR)	AUGMENTED REALITY (AR)	MIXED REALITY (MR)
Level of Immersion	• Completely immersive. Visually transports the user into a fully virtual environment. • High level of isolation from user's immediate physical setting. • Can be accompanied by immersive Audio & haptics. • FOV limited to the hardware capabilities.	• Partially immersive. Visually overlays digital content on the real environment. • Low level of virtual isolation, moderate level of virtual-real integration- user's are visually aware of their immediate physical setting. • Can be accompanied by some audio but no haptics. • FOV is independent of the technology and is same as that of the Human eye.	• Highly immersive. Visually overlays digital content on the real environment. Challenging to achieve high level of immersion in blended reality. • Low level of isolation, High level of integration, user's awareness of their immediate physical setting is important. • Can be accompanied by immersive Audio & haptics. • FOV limited to the hardware capabilities.
Interactivity	• High level of Interactivity is possible. Interaction within the virtual environment can be carried out using hand tracking/controllers/ voice commands/eye tracking/ motion tracking.	• Low level of interactivity. Interaction is limited to the capabilities of the mobile device. Example: Basic gestures, gyroscope based motion, touch screen	• High level of Interactivity is possible. Interaction happens in a blended environment and can be carried out using hand tracking/controllers/ voice commands/eye tracking/ motion tracking. • Interaction is also possible between the real and the virtual objects.
Complexity in Development	• Steep learning curve of current game engines and coding. • Higher level of detailing in design of the virtual environment is generally directly proportional to higher levels of immersion. • Highly skill based- typically requires 3D models, animations, interaction design and architectural design.	• Moderate learning curve, can be built using dedicated user friendly softwares or game engines. • Low to Moderate detailing suffices and does not correspond to the level of immersion. • Skill based- requires 3D models and/or text. Anything else could be additional.	• Steep learning curve of current game engines and coding. • Highest design and technical considerations of all the three XR types due to context-awareness. • The above mentioned are directly proportional to higher levels of immersion. • Highly skill based- typically requires 3D models, animations, interaction design and architectural design.
Hardware requirements	• VR headsets (HMDs) such as Oculus Rift, HTC Vive, Meta Quest 2. HMDs accompanied by controllers. High price point. • 3 DoF / 6 DoF • Core- High computational power, high rendering power. Beneficial- sensors for motion tracking and eye tracking.	• Personal smartphones with back cameras can be used (No expense) or purchase of AR glasses (example; google glasses) which are moderately priced. • 3 DoF • Core- Low computational power, low rendering. Beneficial- Lidar sensors, gyroscopes, internet connectivity and geolocation sensor.	• MR headsets (HMDs) such as the Apple Vision Pro, Microsoft HoloLens and Meta Quest 3. HMDs may or may not be accompanied by controllers. High price point. • 3 DoF / 6 DoF • Core- High computational power, multiple sensors for context-awareness, high rendering power, hand tracking,. Beneficial- eye tracking
IN THIS RESEARCH: 1. **Usability** 2. **Accessibility** 3. **Prototyping**	1. Low usability- Since this research concerns itself with cyberphysical environment hence technology that builds purely virtual environments has little relevance. 2. Accessibility - Student access to VR headsets in the University Research labs. 3. Prototyping - Inadequate and irrelevant	• Moderate usability- AR offers some degree of context-awareness (Marker based/Location based). • Highly Accessibile - Poses low-barrier in terms of development and readily available hardware. • Prototyping- Quick and Easy to build and deploy. Good for low proof of vision/concept. Doesn't showcase provide complete vision of the project.	• Moderate to High usability - MR offers highest context-awareness (Spatial mapping, passthrough). • Low Accessibility - Poses high-barrier and high-reward in terms of development. However, dedicated expensive hardware is imperative. • Prototyping- Time consuming build and easy deploy. Best for proof of vision/concept. Close to accurate representation of the project vision.

Figure 10: Table compares level of immersion, Interactivity, complexity of development, hardware requirement of AR, VR and MR technologies to asssess them for usability, accesibility and Prototyping.

The assessment examined VR, AR, and MR technologies against important common features such as level of immersion, interaction, complexity in development, and hardware requirements to infer how these technologies could contribute to the project in terms of usefulness, accessibility, and prototyping. It was inferred that VR technology holds little relevance due to its complete isolation from the real environment despite its fair accessibility. Hence, they were eliminated from the design and development process. It became clear that MR was best suited for the final production despite its accessibility and prototyping challenges. However, the current MR development pipeline appeared too cumbersome for quick initial development and testing of the concept. It was soon realized that AR could address this gap as it offered some degree of context-awareness and readily available hardware while posing a low barrier to development. Hence, it was decided to employ AR for initial prototypes and MR for final production.

Two different types of augmented reality tests were conducted. Both types used unique techniques and had a unique goal. However, they all explored the same question: How can we embed virtual objects in physical space?

4.1 Prototype 1: Room as a Target in AR

Generally, Smartphone-based AR apps use computer vision technologies to recognize markers, such as QR codes or images, and overlay geometry assigned to the marker. However, since the physicality of the real environment is fundamental to this research, it seemed best to turn the environment itself into an AR Marker.

This was achieved using the Area Target feature by an AR development platform called Vuforia Engine. A room-scale 3D scan of the target room was generated using a smartphone’s LiDAR sensor and fed into Vuforia’s Area Target Generator, which trained the model to generate a Unity package, a collection of files made for the Unity3D game engine.

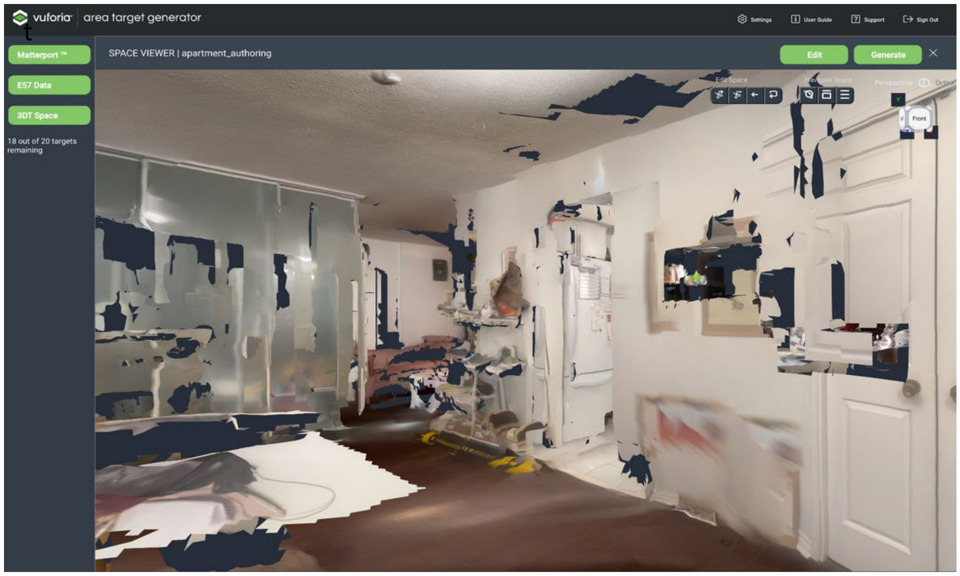


Image 11: Screenshot of the area target generator window showing the 3D scan capture of the room.

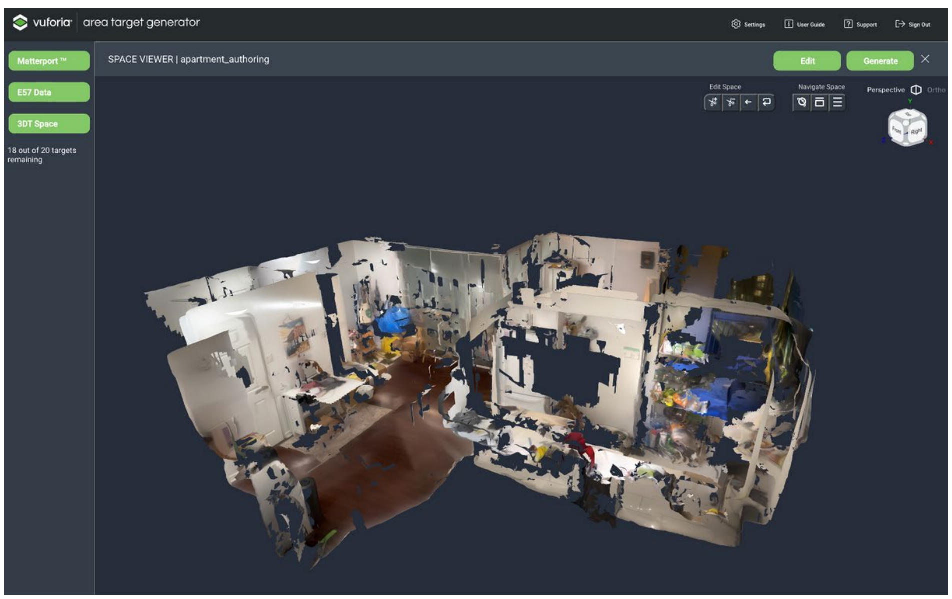


Image 12: Screenshot of the area target generator window showing a top vie of the 3D scan of the room.

The Unity package was then imported into Unity with the Vuforia plugin installed in Unity to overlay the desired geometry. The application was then built and installed on an Android smartphone. When opened, the app would use the back camera to scan the room and overlay the geometry.

What made this unique is that, unlike other QR code-based or image-based markers, the marker wasn't portable, meaning this AR experience could only be experienced in that one specific location. The place hence became the center of the experience. The physicality of the room surrounding the user became the marker instead of a flat 2D image. When the virtual geometry appeared, it gave the sense of a revealed hidden layer of the environment or 'the invisible that was made visible.'

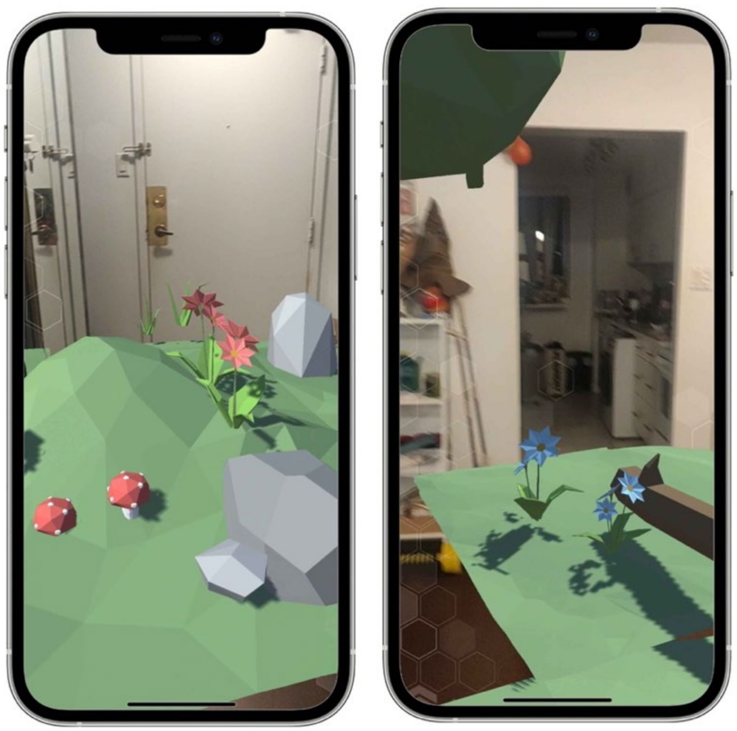


Image 13: Captured Screenshots of the Room-based AR, later edited in Photoshop to add a phone frame for visualisation purpose.

4.2 Prototype 2- Blended Objects

This exploration took a different approach as it was not concerned with the real environment or a physical space but interested in examining a dialogue between its four major components. The objective was to create two physical objects with a flat surface that could be turned into image targets for AR detection and then assign and anchor a different virtual geometry to each of the two image targets. Then, the crucial part was to examine how the objects' physical intersection corresponds to the virtual intersection of their respective geometries. The schematic diagram below shows how different components came together in this AR test.

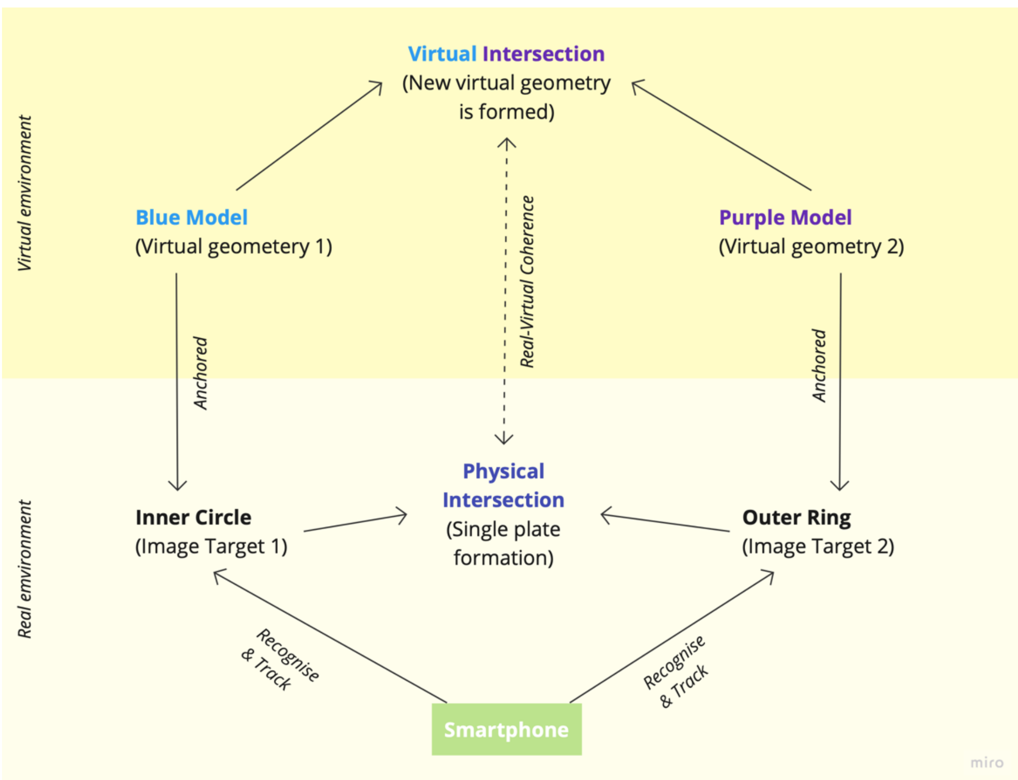


Image 14: Show the relationship between the Real-physical parts and the Virtual parts. It highlights the real-virtual coherence achieved in this prototype creating a 'blended object'.

First, two image targets were designed with certain constraints in mind, such as: 1) the shapes had to be simple and flat, and 2) when put together, they had to combine to form one simple object. Hence, an outer ring and an inner circle, as illustrated in Figure 11, were laser cut and hand painted, with a base stand to support them.

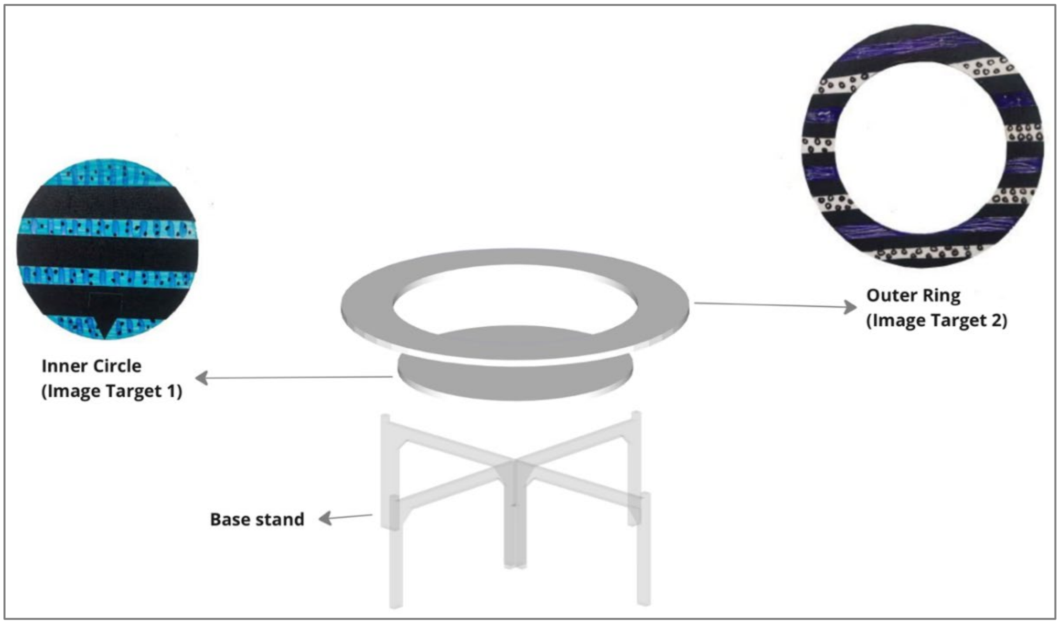


Figure 11: Illustration shows the physical components used and their assembly.

Figure 12: View showing the 3D model of laser cut base stand with the Outer Ring and Inner Circle.

Next, a 3D model was made inside of Sketchup 3D (Image 15) keeping the constraint that, it would be a seamless composite of two independent geometries that could be individually exported an FBX files.

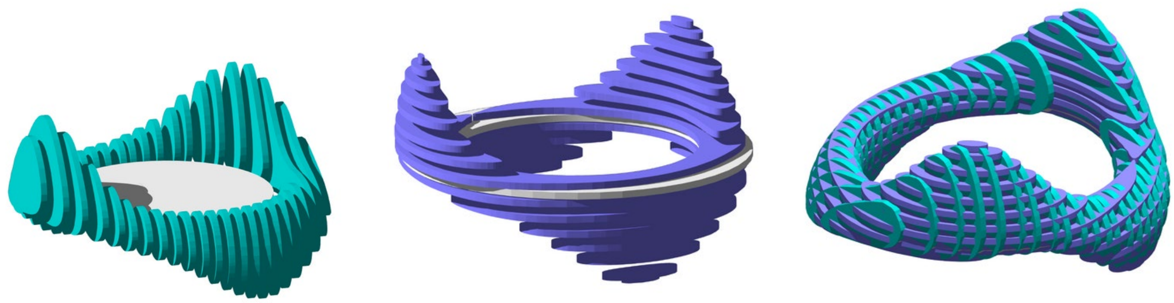


Image 15: Assembled view showing intersecting Ring and Circle

Vuforia Engine's Image Target platform was used to produce Image targets that were then fed into the Unity 3D game engine. The targets were then assigned their corresponding geometry and position to align with their physical counterparts as seen in Image 16.

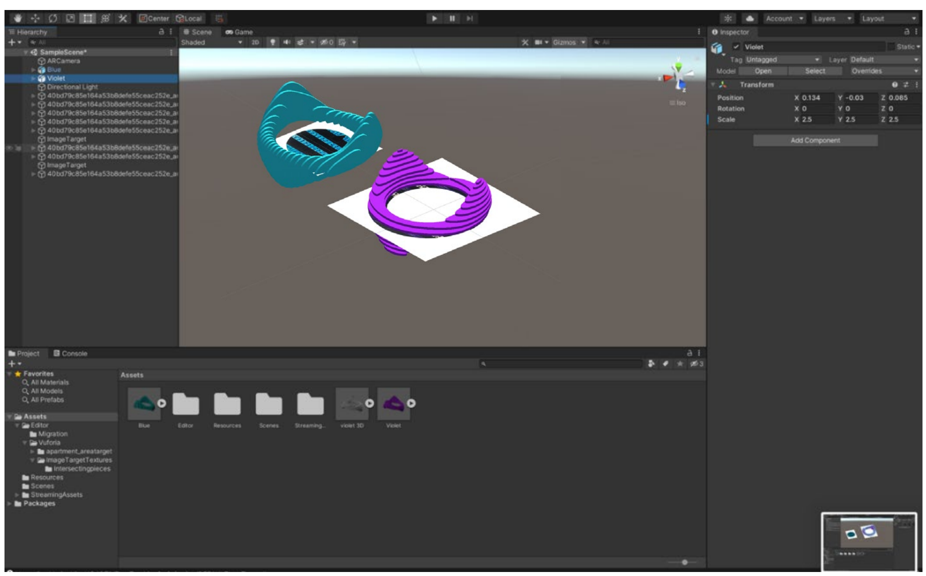


Image 16: Screenshot of Unity showing the image targets and their corresponding geometry.

The App was then built and tested. When opened, the app recognized and detected one or both of the Image Targets at a time. When the Inner circle Image Target was placed within the Outer Ring Image Target, their respective virtual geometries intersected, too. When the former was aligned inside the latter in a certain orientation, a torus-shaped geometry formed by design.

Image 17: Screenshots edited to add smartphone frame, shows the final blended object.

4.3 Findings from Prototype 1 and Prototype 2:

	Prototype 1: Room as a Target in AR	Prototype 2: Blended Objects
Visibility	The smartphone only showed virtual objects located that were positioned directly infront of the camera's FoV at any given point. Hence, the virtual objects positioned elsewhere were not visible unless the camera's direction changed.	By the nature of how image targets work, framing the complete image in the camera is important for detection, however small or big. Hence, the corresponding virtual geometries of the targets were always completely visible.
Position and scale	The area target geometries were positioned at various points on the floor and, In some instances, went up to the ceiling. The virtual trees were scaled to reach the ceiling of the room, and the flowers were scaled down to be small and toward the floor. Area Target gave the sense of being surrounded by virtual geometries that populated the room.	These were designed to be relatively small physical objects. To achieve the perfect emergent intersecting virtual geometry, it was crucial to match the precise position and scale of the virtual counterparts to those of the physical image targets.
Bodily Movement	Full body engagement: It encouraged the bodily movement of looking up at the trees and down at the flowers. It also encouraged me to walk closer to the virtual objects for a better view.	Isolated body engagement: Picking up the image targets by hand and trying different alignments was a core aspect of this experiment that made it interesting.
Interactivity	Additional interaction, such as user input, was absent.	Additional interaction such as user input was absent.

Figure 13: Comparison table assesses the visibility, position & scale, bodily movement and interactivity of the two prototypes.

Having virtual objects outside the FoV that could be made visible by simply 'looking' at it with the device created a sense of higher immersion in Prototype 1. The 'sense of being surrounded' also contributed to a new sense of 'place' that arose from and was unique to the real-virtual experience. However, capturing a virtual object in its entirety appeared applicable to interactions requiring close inspection, such as in Prototype 2. These explorations made it abundantly clear how important the position and scale of the virtual objects was in relation to the physical room. It had a direct impact on engagement, interactivity, and perception of the AR experience. Two types of engagements were noticed - active and passive engagements. It was helpful to decipher and learn how they complement each other. Prototype 1 engaged the whole body, while Prototype 2 relied on eyes and hands. Prototype 1 urged the user to engage in observational engagement, while Prototype 2 encouraged creative engagement.

The use of Area Target in Prototype 1 helped moving the research towards context-specificity, as the AR experience was custom to the room's architecture and could only be activated by it. This also acted as the first proof of concept for context-specificity and negated the empty-room phenomena prevalent in XR. Being able to track the movement of a physical object, use its appearance, and physically touch/lift/rotate it with continuous virtual feedback helped in understanding how real-world materiality could be brought to life in virtuality.

05. DESIGN, DEVELOPMENT & DEPLOYMENT

5.1 Scenario Building

5.1.1 Goals:

The final design was imagined as one corner of a larger retail store designed in mixed reality architecture. Since the design takes a context-specific approach, the real-world context for this prototype becomes essential. The prototype was designed to be deployed and exhibited at the Digital Futures Graduate Exhibition of 2024, held at OCAD University's waterfront campus at Artscape Daniels, Toronto. Hence, this imagined retail corner was designed and built, both physically and digitally, keeping in mind the architectural features and constraints of the exhibit space.

The prototype and the production process intended to serve the following purposes:

- Act as a minimum viable product for the proposed mixed reality architecture.
- Explore tools and derive a suitable workflow for mixed reality architectural production.
- Investigate each major stage of production: concept, build, and deploy.
- Develop design frameworks and techniques.

As seen in the previous chapter, the use of Area Target helped move towards context-specificity, as the AR experience was tailored to the room's architecture and could only be activated by it. This also acted as the first proof of concept for context-specificity and negated the empty-room phenomena prevalent in XR. Being able to track the movement of a physical object use its appearance, and physically touch/lift/rotate it with continuous virtual feedback helped in realizing how real-world materiality could be brought to life in virtuality.

5.1.2 Scope of the Prototype

This research investigates mixed reality architecture in the context of a retail store as it presents several opportunities. The interior design of retail stores is driven by dense integration of analogue and digital media that offer opportunities for implementing immersive and interactive technologies. Retail stores can be designed to be of any size, from kiosks to hypermarkets, and for any length of time, such as pop-up stores or multi-generational storefronts. These attributes meant that the designed prototype could be contained to the design of a small corner of a larger imagined store and still be easily conceptually scalable to the rest or many such stores.

The focus of this research considerably narrows down the possible and relevant prototypes to interior spaces of architecture rather than large architectural buildings, building complexes, or urban spaces. Working with architecture of human scale is crucial to this research due to the scale of interior spaces, factors that affect embodiment in MR experiences and also the current technical constraints of MR devices, such as the 3-meter proximity limit on spatial anchors to avoid the 'drift' effect which causes inaccuracy in spatial mapping. These are some of the many technical constraints that inform the design. While the current technical factors are bound to change as the technology advances, allowing for greater flexibility on the constraints one has to consider in such a process, the core workflow and process will continue to be relevant.

In the future, we may be able to design mixed-reality architecture that caters to large real-world architectural buildings and urban spaces; however, this research's principal prototype investigates the creation of one such interior space.

5.1.3 Establishing Context

The purpose of this prototype was to adopt and test the Context-specific design approach proposed for MR environments. Hence, it was essential first to establish the meaning of context in this prototype.

A fictional client, a brand that sells bath and body products, was created to get specific information about the types of products, experiential values, storage, interaction, and overall aesthetic. A brand profile was generated using ChatGPT, as seen in Figure 14, which was useful in setting a background for the retail store. However, to get more specific about products and product information, some bath and body products were bought from the local stores (Image 18).

Brand Name: Aqua Immerse

Aqua Immerse focuses on creating a transformative retail store space that not only showcases the products but also encapsulates the essence of relaxation, rejuvenation, and sensory delight through an immersive experience.

Core Values:
- Quality: Commitment to the highest quality ingredients and materials.
- Sustainability: Dedication to eco-friendly practices and packaging.
- Well-being: Fostering physical, mental, and emotional well-being through our products.
- Innovation: Continuously innovating to enhance bathing experiences.

Product Range:
- Bath Bombs: A variety of scents and therapeutic properties.
- Bath Salts: Mineral-rich salts for detoxification and relaxation.
- Body Brushes: High-quality brushes for exfoliating and stimulating circulation.
- Bathrobes: Luxuriously soft and absorbent robes for a spa-like experience at home.
- Scented Candles: A selection of candles to set the mood and enhance the bathing ambiance.

MR Experience Goals:
- Immersive Environment: Create a virtual space that transports customers to a serene, luxurious spa setting, highlighting the transformative power of our products.
- Interactive Product Demonstrations: Allow customers to interact with our products virtually, understanding their benefits and application.
- Customization: Offer personalized recommendations and customizations, enhancing the customer's journey to relaxation and well-being.
- Educational Content: Provide valuable information on the benefits of each product, tips for creating the ultimate bathing experience, and the importance of self-care.

Target Audience:
Individuals seeking premium, sustainable bathing products that offer a sanctuary of relaxation and rejuvenation in their daily lives.

Figure 14: Brand Profile and brief produced by ChatGPT (AI, personal communication, February 18, 2024)

Image 18: A collection of images show the different products gathered for scenario building.

Apart from the thematic context, the principal prototype in this research responds to three types of contexts: physical, Temporal, and User. Through these broad categories, we refer to specific features and aspects that make up this MR environment. The flow chart in Figure 15 details this further.

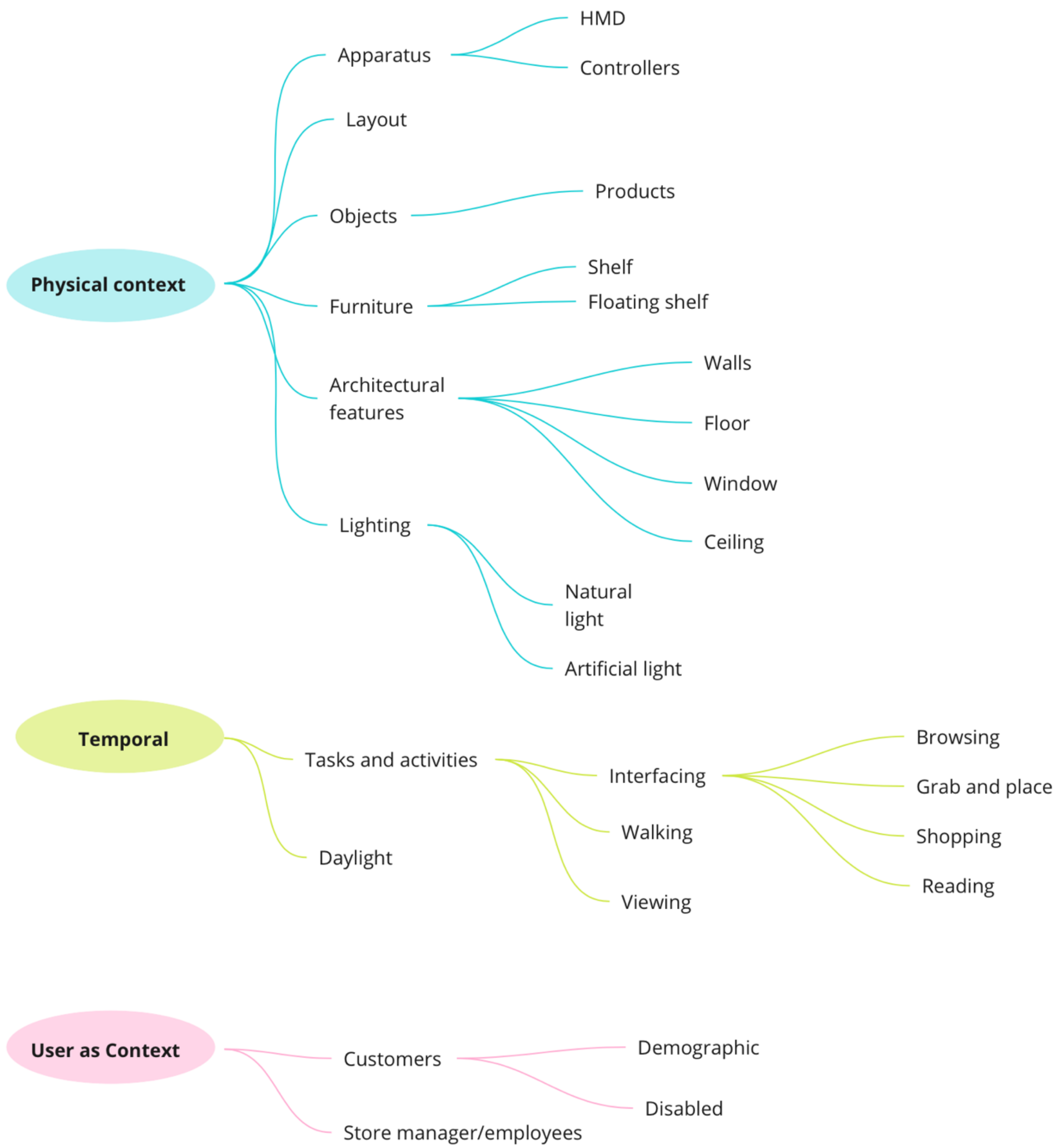


Figure 15: Shows different types of context involved.

5.2 Concept Development

5.2.1 Between the Body and the Built

This process began with making sketches of pop-stores, as by nature, pop-stores are not only small, compact, and functionally whole spaces, but they are also spatiotemporal setups much like MR experiences. The first series of sketches as seen in Figure 16 explores design relationships in pop stores and retail spaces, focusing on how the human body perceives and engages with the built envelope of such architectural spaces. The built envelope here refers to the essential elements that define an architectural space, such as the floor, ceiling, columns, door, windows, platforms, and stairs.

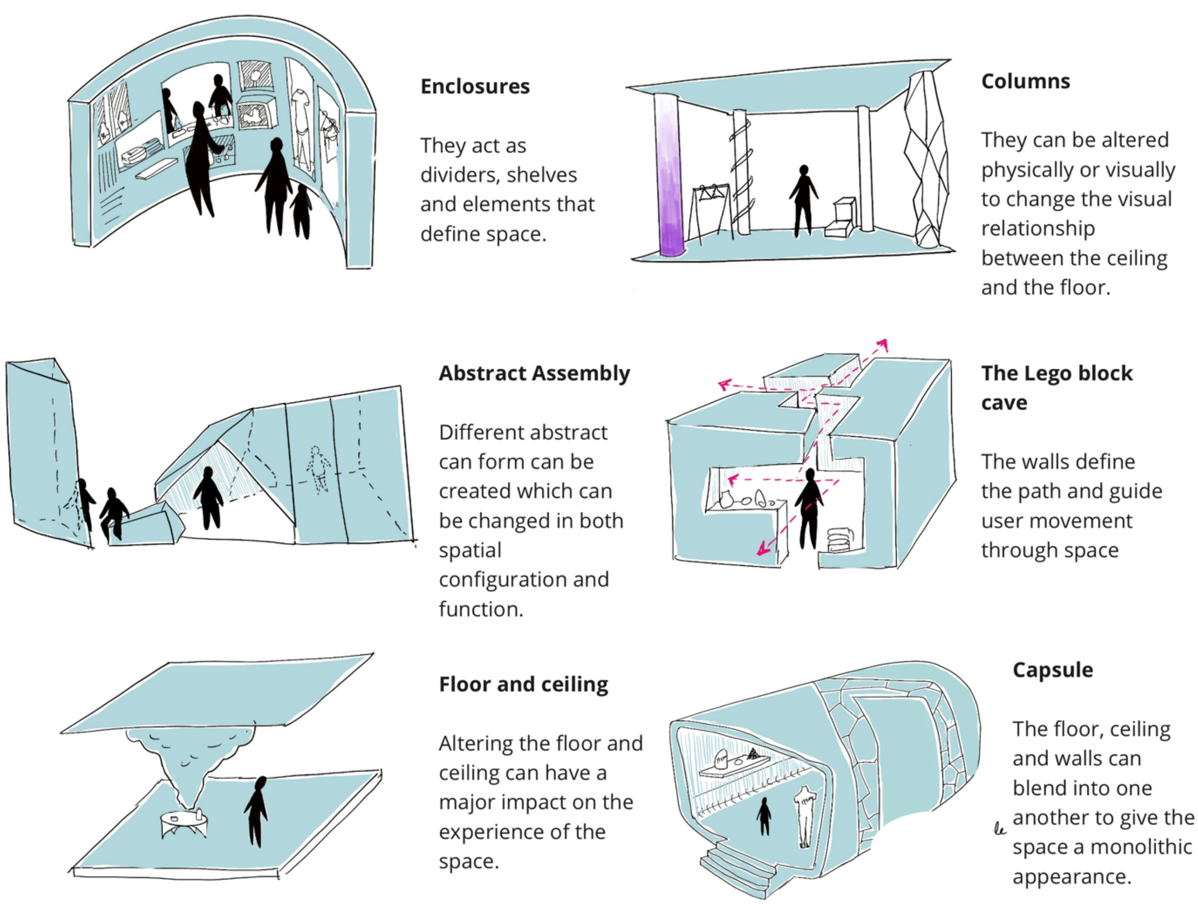


Figure 16: Shows design of retail spaces as built form in relation to human movement and perception.

The initial sketches highlight how these elements of architecture could be designed to engage the human body and perception. This also helped visualize the scale of the final production. However, these initial sketches also became the starting point for conceptualising real-virtual spatial designs through simplistic drawings. The challenge was to design and build both the real-world and virtual sides of the environment simultaneously.

5.2.2 Spatial Co-Location, Affordances and Signifiers

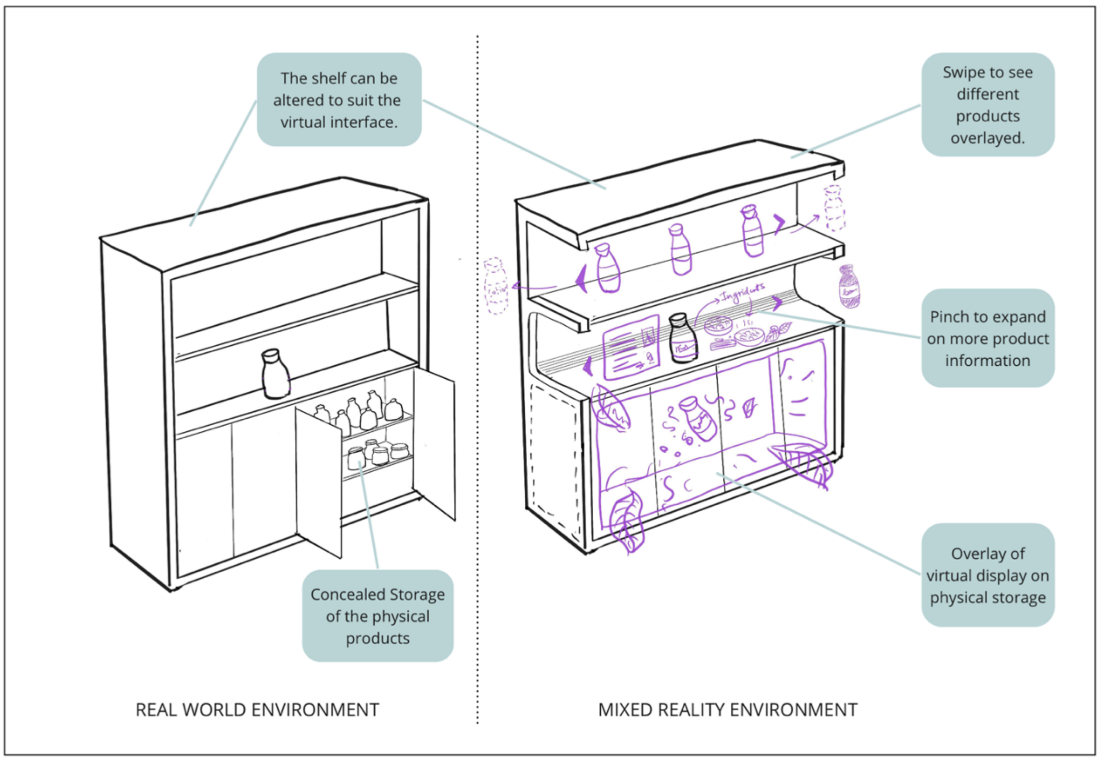


Figure 17: Shows a real-virtual retail store shelf. Isometric drawing prototype.

The illustration above shows an initial concept drawing of an MR storage/display shelf. It was made such that a typical shelf's familiar form and function would be retained with added virtual interactions commonly found in smartphone interfaces and on e-commerce websites. It shows how a shelf would appear in the real-world environment (left) and how the same shelf would appear in an MR environment (right). Here, attention was paid to how virtual elements would blend with real objects for not only cohesion and alignment but also information layout and retrieval. This was achieved using some useful concepts from user-experience design and geospatial research.

a) Co-location: Two types of co-locations can occur in virtual and mixed reality environments- Social co-location and spatial co-location. Social co-location occurs when two or more humans are simultaneously present inside the same VR or MR environment, whether sharing the same physical space or through telepresence. While social co-location could be valuable in a semi-private space like retail, designing for shared MR experiences is a significant undertaking that lies outside the scope of this research.

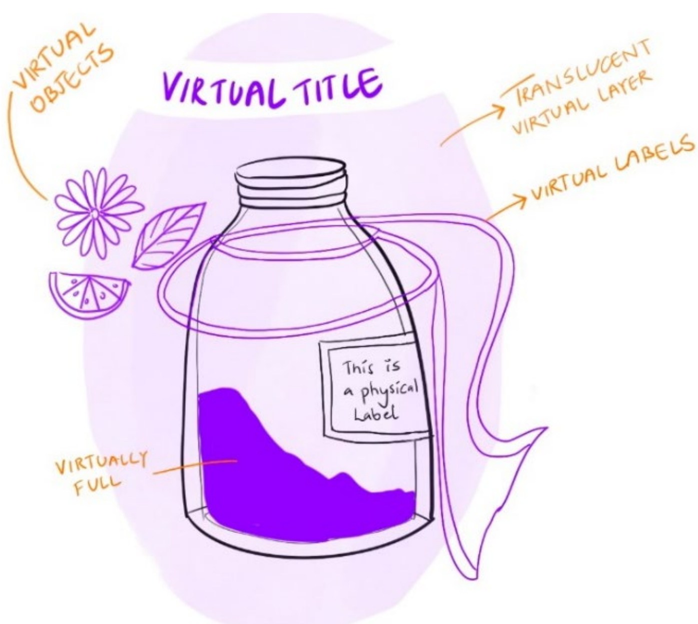


Figure 18: Sketch showing an example of virtual co-location in retail.

This research uses the second type of co-location, spatial co-location, (Figure 18) where virtual objects appear to blend in with the user's real environment such that they appear to be 'really there'. For example, in the Figure, the 'real' bottle, shown in black, is overlaid with virtual ingredients, virtual text, the virtual substance inside the bottle, and a virtual bottle label, all shown in violet. The concept of spatial co-location here helps bring virtual and real elements together in an MR environment so that they complement and enhance each other.

b) Affordances and signifiers: The purpose of the shelf in this MR scenario, beyond the typical functions of a shelf, is to act as a signifier in an MR environment. Familiar interior and architectural elements like a table, a chair, a staircase, etc, can act as signifiers in a spatial interface if designed so. In User Interface design, a signifier is any visual element that holds cues or indicators for possible actions. They tell the user what can be done and how one can do it. When users see a shelf, they expect to find objects on display and interact with them (Figure 19).

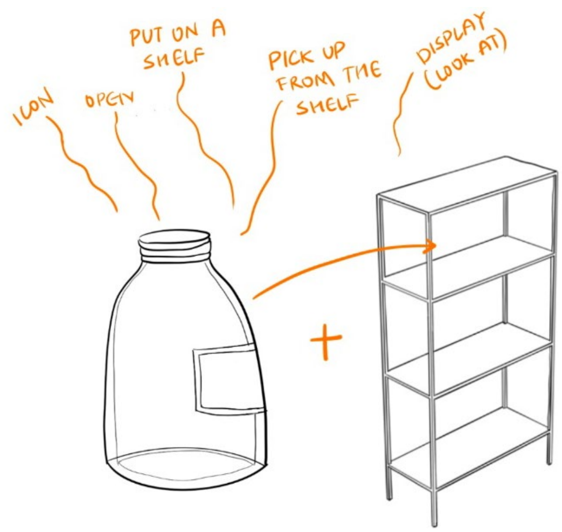


Figure 19: Sketch shows physical affordances and signifiers.

5.2.2 Zoning – An architectural planning principle for MR environments

Figure 20, conceptualizes an MR interior store environment, showing how users can engage with different spaces or zones within an interior space. Zones help differentiate areas based on functional aspects and land use, which help systematize the design and decision-making process. Usually, the users are rarely made aware of their zone unless they are near a 'restricted zone' or a 'surveillance areas'. However, visual indication of zones can be used in MR environments to enhance the user's in-space experience. The illustration below shows how zones could effectively be used in the design of an MR environment.

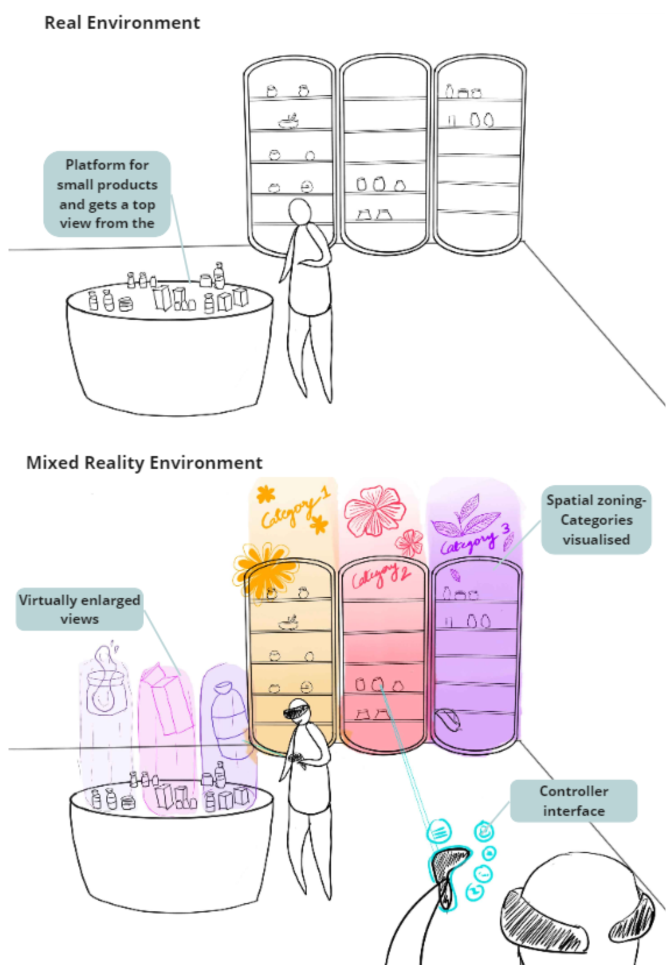


Figure 20: Sketch shows some basic zones that could be made visible in an MR environment.

Zoning in an MR experience can be used to create structured, intuitive, and efficient MR environments that help users navigate both the virtual and real environment. Moreover, after examining how zoning is currently used as an architectural planning principle, a taxonomy for MR environment design was proposed. The taxonomy identifies different types of zones and then outlines their characteristics and functions. The different types of zones are Interaction zones, Display zones, Navigation zones, and restricted zones. The

Figure below shows how some of these zones could also be 'made visually visible' to the users inside an MR environment.

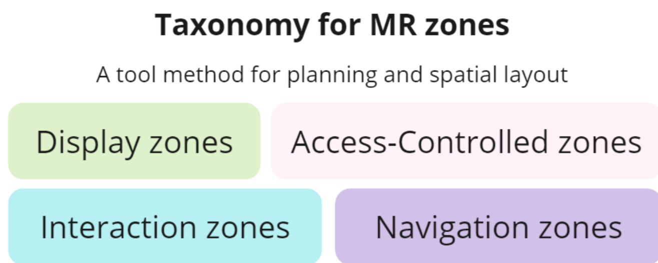


Figure 21: Shows the proposed taxonomy for designing MR environments.

a) Interaction zones can be designed for user engagement by considering several factors, such as the ones listed below.

- No users at a given time.
- Average interaction time per user. This will help in anticipating the rate of flow of users that occupy an interior store space.
- Level and types of interaction—This refers to how active or passive an interaction is. For example, a game-play interaction could be physically stimulating and require a controlled access area, while a meditative experience in MR could require a zone with no distractions.
- Material requirements - Certain interactions may require specific types of materials to enable or support an MR experience, such as padded flooring, high luminosity, a window with a view, etc.

b) Display zones are meant mainly for viewing rather than interaction; the viewing could be associated with a real or virtual or a real-virtual viewing in a space. The following factors could affect it:

- The vantage point of users: Since the elements in space are locked to the real environment, the positions and orientation of the users are crucial.

- Interactive viewing: This overlaps with some factors of the interaction zones to some capacity; however, the primary purpose still remains viewing, hence paying attention to the mechanisms of an interactive display such as a play-pause interface, expand gesture, zoom in & zoom out gesture become important.

c) Navigation zones: Like architectural spaces, navigation zones in an MR environment are real environments that facilitate users' movement and orientation within an MR environment. The following factors could be considered:

- Connectivity—They form connectivity between different zones and hence regulate movement, order, and exchange between them.
- Ease of movement—These zones witness the densest physical movement of users and should ideally not contain points in space that cause users to stop and accumulate. They should not be interrupted by physical or virtual elements unless by design.
- Wayfinding: These zones must help users find their way to different destinations inside an architectural space and control their movement.
- Liminal experience: These spaces are not devoid of experiential value and should not be designed to be so. Similar to how thoughtfully designed liminal spaces in architecture can turn dull transitory spaces into 'spaces to breathe' or 'spaces to pause' (example: courtyard), liminal spaces in MR architecture could be beneficial if designed correctly.

d) Access-controlled zones: It is a large category encompassing spaces that demand minimal customer access. In a way, a semi-public space such as a retail store is generally access-controlled. However, if one looks closer, one will see that spaces and functions inside them vary in terms of levels of freedom they offer to their different user groups.

- Staff-only access: These areas are essential to the function and upkeep of retail stores and are restricted from customers. Visual and physical boundaries play a crucial role in MR to ensure customers don't accidentally stray from such areas.

- Regulated access: Such areas require rules to regulate access. Examples include ticketed in-store events, promotional events, trial rooms, etc. The rules can be imposed in MR environments through virtual signs, audio announcements, and prompts that activate when a user approaches an access-controlled zone.

These categories are loosely framed to cater to MR architectural design broadly. While this isn't a highly structured and compact framework because of the nature of the concepts it deals with, it does not mean the framework is not useful. Irrespective of the type of MR architectural project, this framework can serve as a good starting point for designers to assess and play with functions, aesthetics, and visuals of an MR environment.

5.2.3 Floor Plan using Zoning Taxonomy

The MR zoning taxonomy is used to prepare the floor plan for the final prototype. As seen in Figure 22, the principal prototype is divided into four components: the shelf, the floating display, the Wrist cart, and the Augmented architecture. Each component is designed as a distinct mixed reality interface that blends the physical and digital.

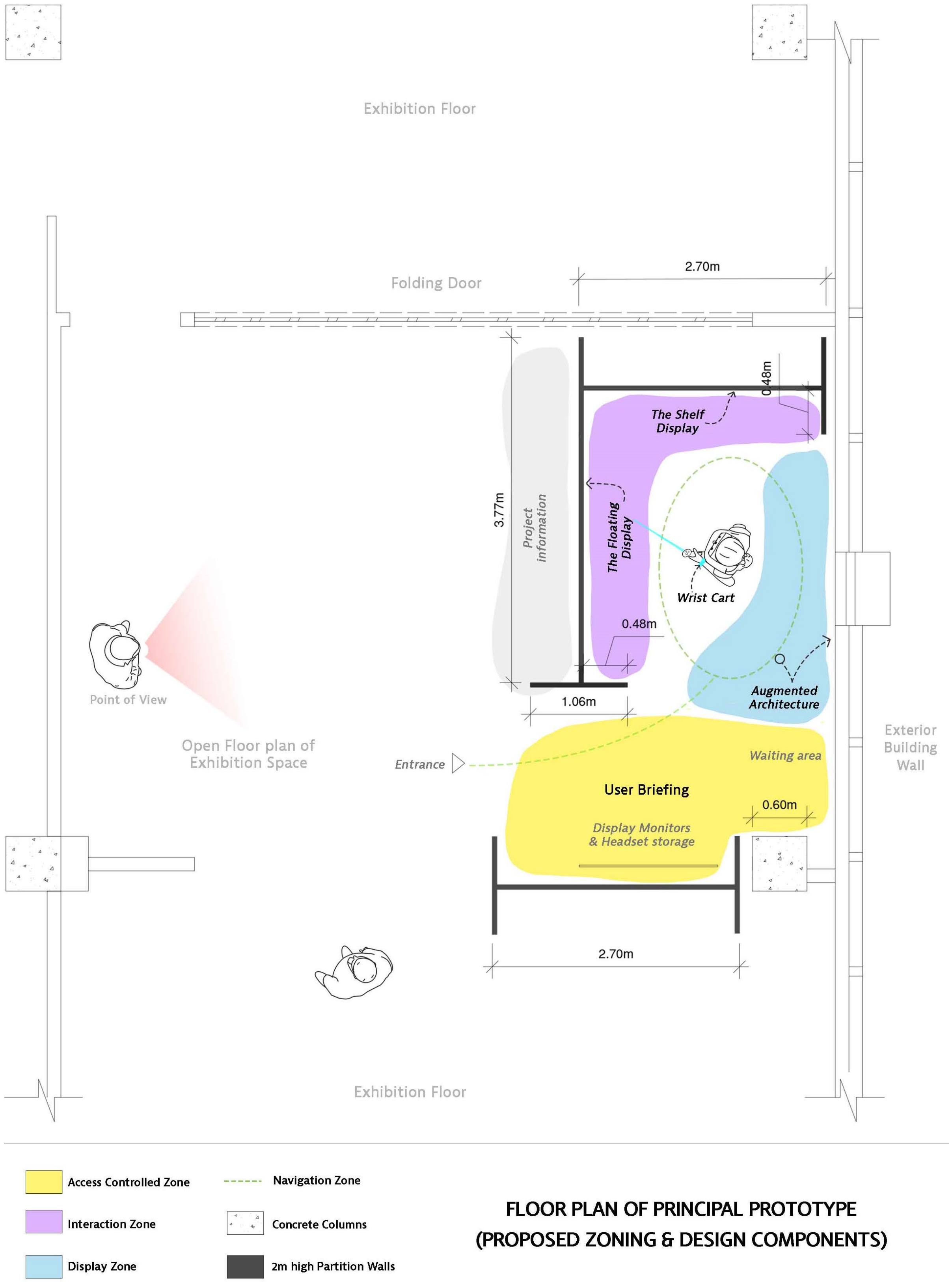


Figure 22: Floor plan of the MR store corner

5.3 Design, Code and Build

5.3.1 3D Model and Digital Twins

The on-site location of the exhibit was marked and measured. The measurements were used to make the floorplan (Figure 22) and to make a digital 3D model (Image 20).

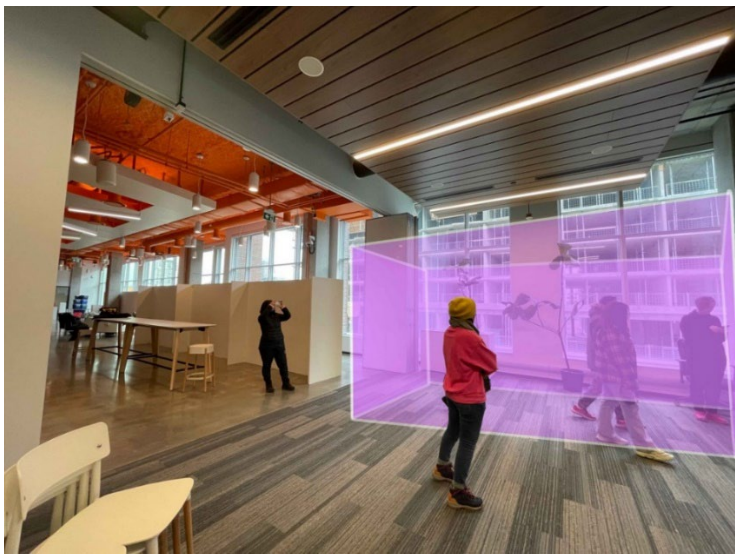


Image 19: Point of View - Image showing the exhibition space.

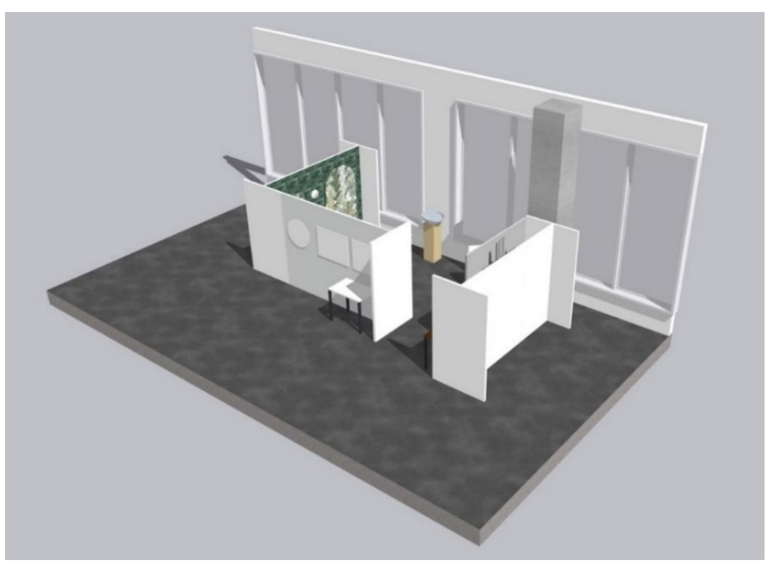


Image 20: Sketchup 3D model: View of the proposed design

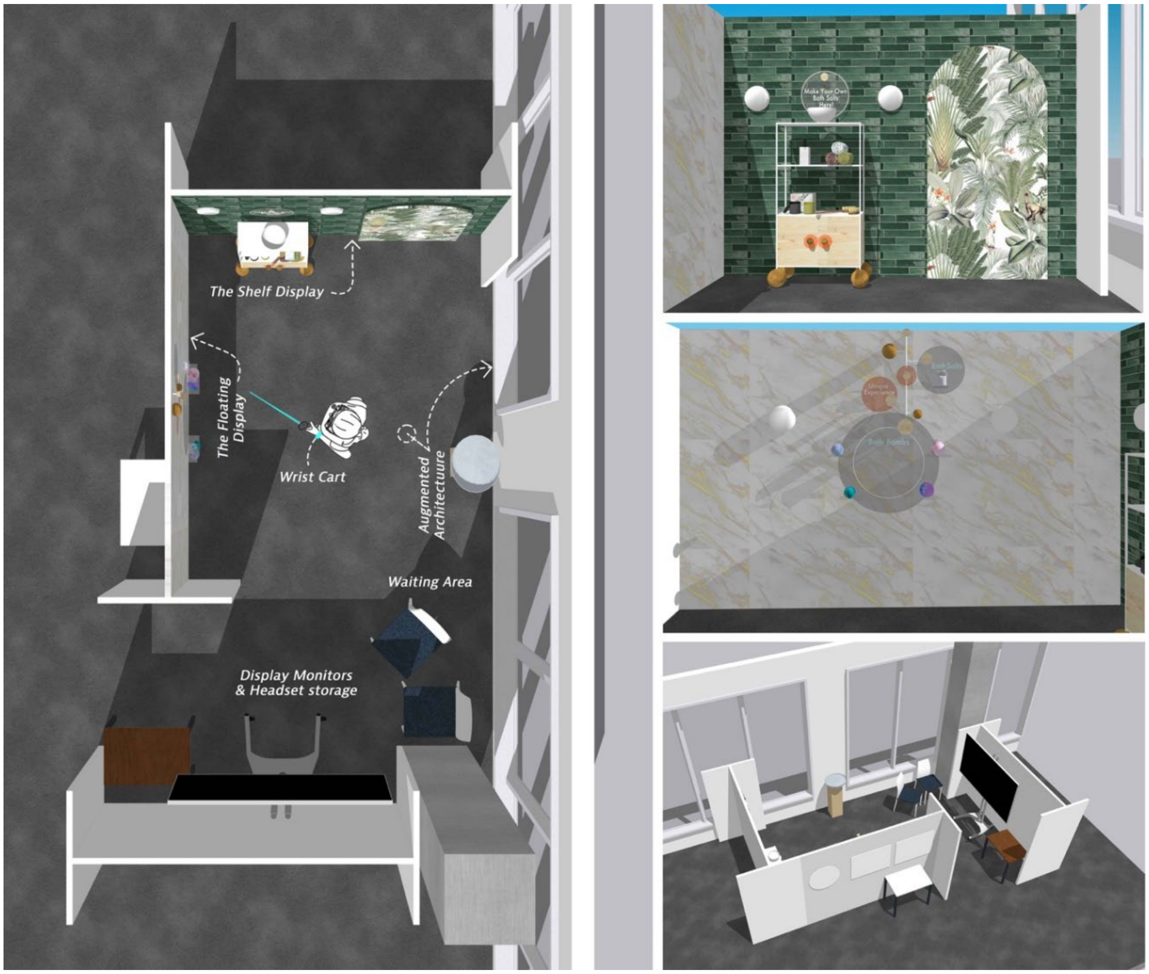


Image 21: Annotated Perspective Views of the 3D model.

Typically, in architecture, a 3D model is used for visualizing spaces and materials, planning circulation and flow of light, and analysing several other spatial relationships. However, in producing the MR environment, the 3D model was also used as a digital twin. The 3D model contained several individual models of the furniture. The modelled furniture were exported out as separate geometries to be used as virtual copies of the furniture. These digital twins were not only essential for a 1:1 scale reference of the real furniture but were also important for occluding the real with the virtual. The model was useful for planning how the real furniture and objects would occupy space alongside the virtual elements. It was also useful for speculating how humans would use their bodies while interacting in an MR environment, for example: interacting with a shelf platform that was too high or too low.

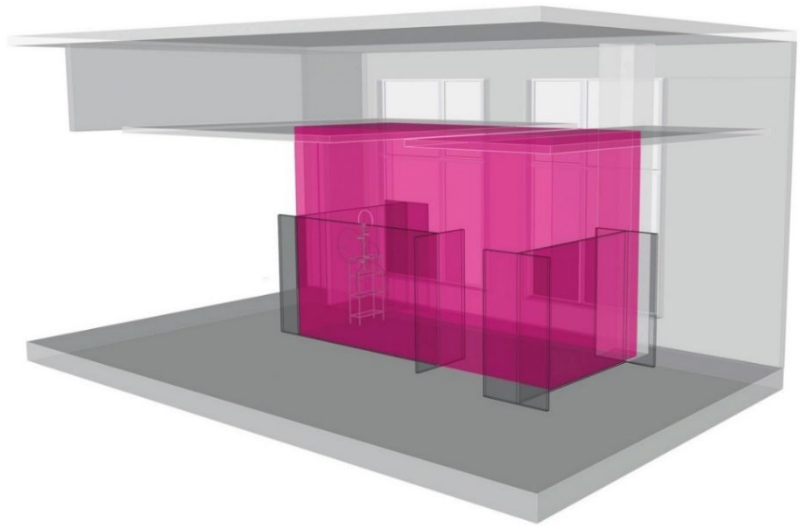


Figure 23: Shows the bounds of the Room Scan

The ‘walls’ that were set up in the room scan were a combination of temporary walls and the building's wall.

The ceiling height and plane were locked to the false ceiling in the room.

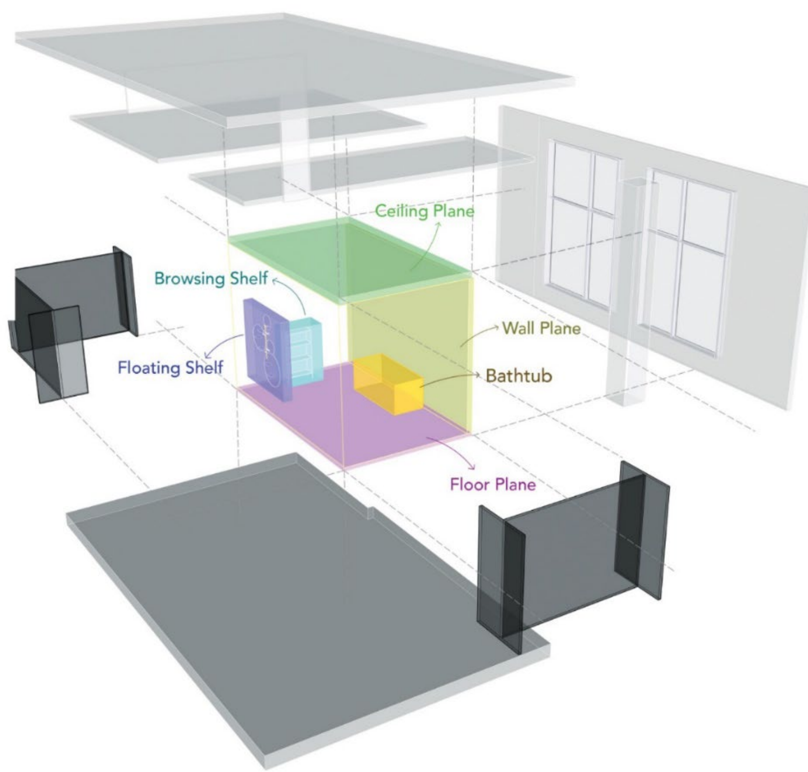


Figure 24: Exploded view shows spatial configuration of different components.

The exploded view in Figure 24 shows the geometrical planes and volumes that assemble to form the walls, floor, and ceiling in the Room Setup of Meta Quest 3. It gives an overall view of how different blocks of furniture as well as the architectural components were defined and arranged to achieve the final spatial configuration. All the components that are shown in colour in the figure were made into digital twins. Which were then used inside the game engine for further development.

5.3.2 The Browsing Shelf

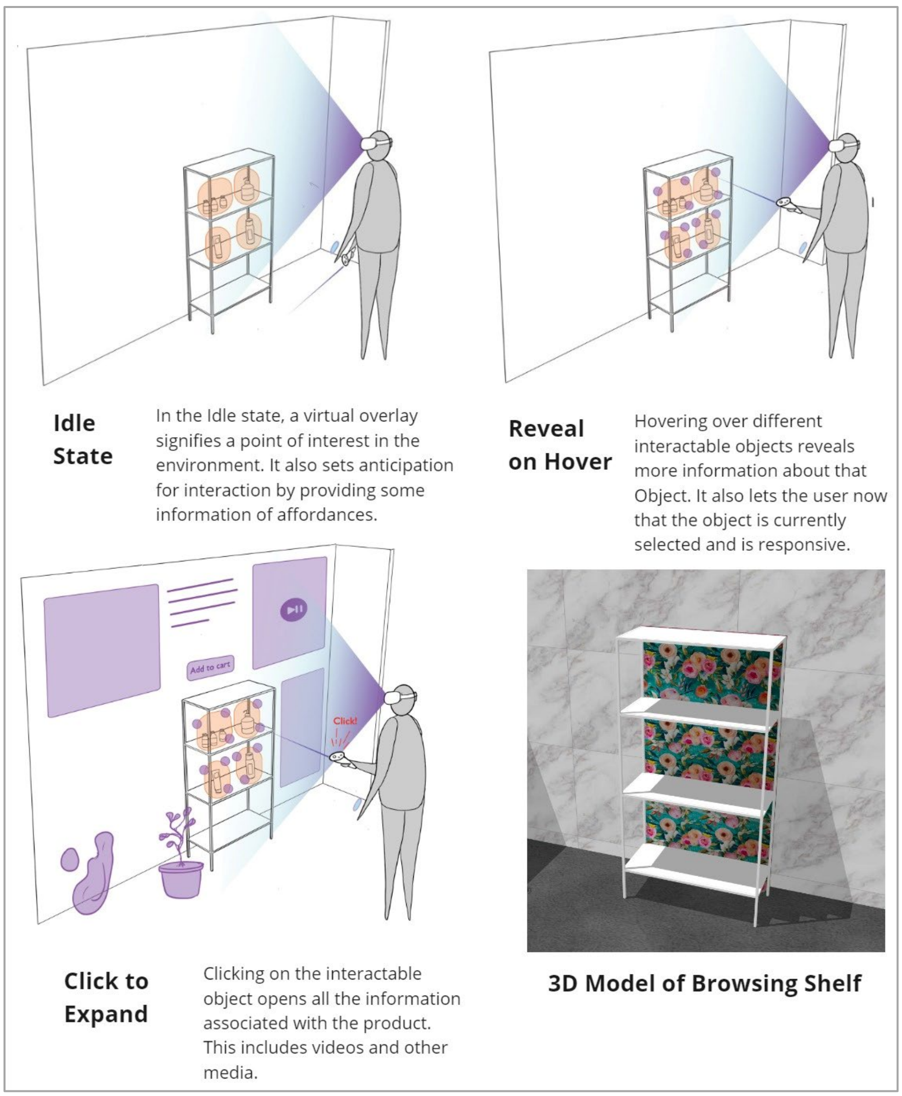


Figure 25: Interaction Design for the Browsing Shelf

The Browsing Shelf was designed as a Mixed Reality display shelf that along with performing as a typical retail display shelf would also allows users wearing the headset to interact with the products virtually. The products were placed on the shelf and the information about the products was mapped in reference to the position of the products. The illustrations in Figure 25 show the design of user interaction.

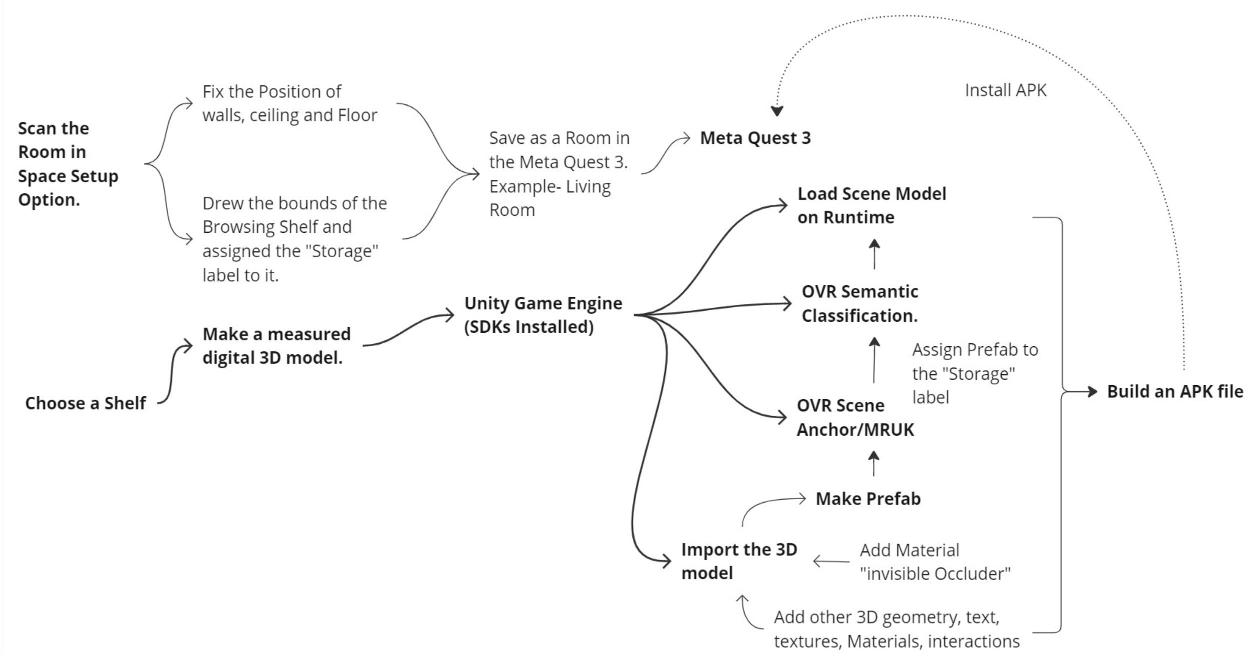


Figure 26: Workflow for the Browsing shelf

The workflow for building this component is detailed out in Figure 26. It shows how the shelf's digital twin was imported into the game engine, made into a prefab, and assigned to a label in the OVR semantic classification to differentiate it from the other components of the Scene Model of a scanned room. Later, similar workflow was used for building other components.

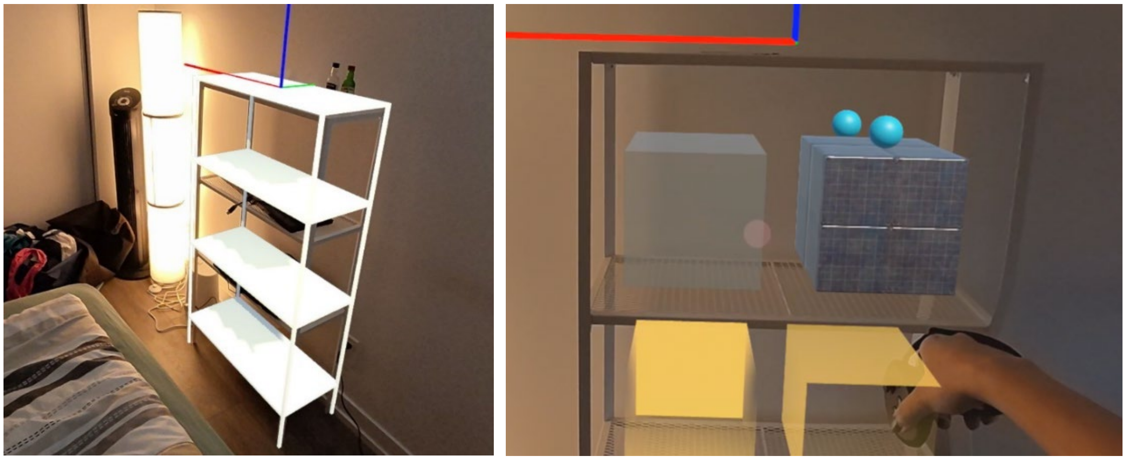


Image 22: (Left) Show co-location of the real world object with the virtual mesh geometery that was modelled in Sketchup. (Right) Show the development pictures of the real-virtual shelf display where the shelf has an occlude material on and also has collision. The real shelf has virtual objects placed on it.

Perfecting the design of the shelf, like all other components, was an iterative process. It involved making edits in the game engine, building the app into the Meta Quest 3, testing the edits to make notes for improvement, and making edits based on those notes back in the engine. The image above (left) shows the alignment of the digital twin to the real shelf in the MR environment and (right) shows the same component with an 'Invisible Occluder' material applied to it to turn the geometry invisible in scene. Here, the virtual objects also appear to be 'placed' on the real shelf, an example of co-location.

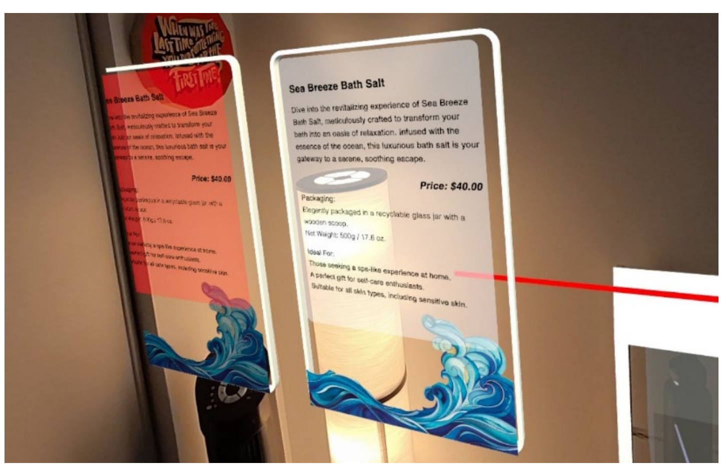


Image 23: Screenshot shows the browsing interface for the bath products as seen in MR.

Through the iterative process, more details were added regarding different types of information layouts, textures, geometries, and video formats. An example of a product information layout is shown below.

Image 24: Screenshot shows the "on click" view of one of the products on the browsing shelf as seen in MR.

5.3.3 The floating shelf/ Customization shelf

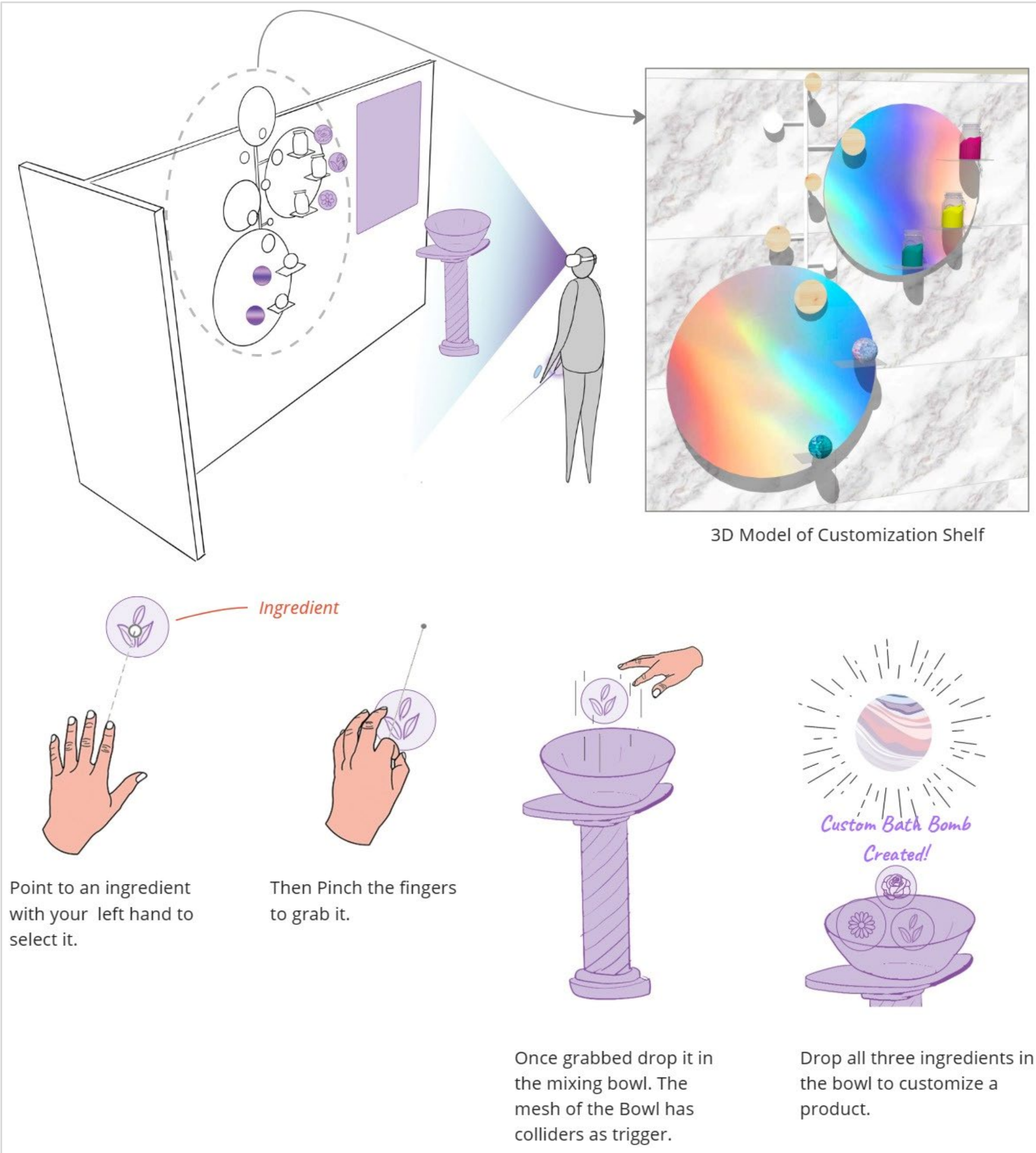


Figure 27: Interaction design for the Customization shelf/ Floating Shelf

The process of building in MR for this shelf was largely similar to that of the Browsing Shelf. However, this was designed as a hands-free experience, and hence, all the interactions were unique to the component. Figure 27 shows how different hand poses were used to create embodied interactions.

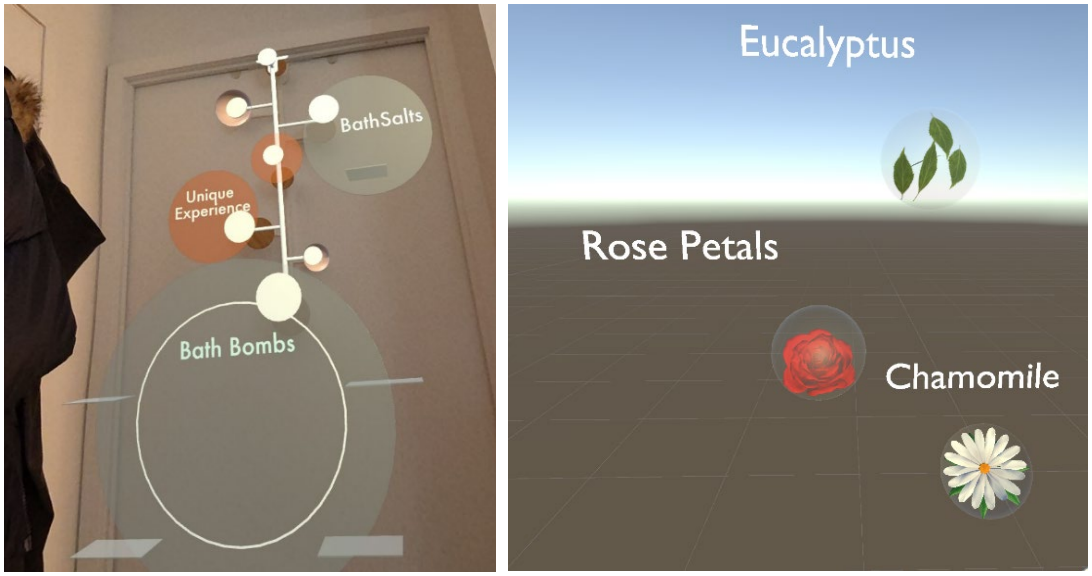


Image 25: (Left) The floating shelf interface co-locates with the door hanging element. It also shows legible text for browsing. (Right) Ingredients

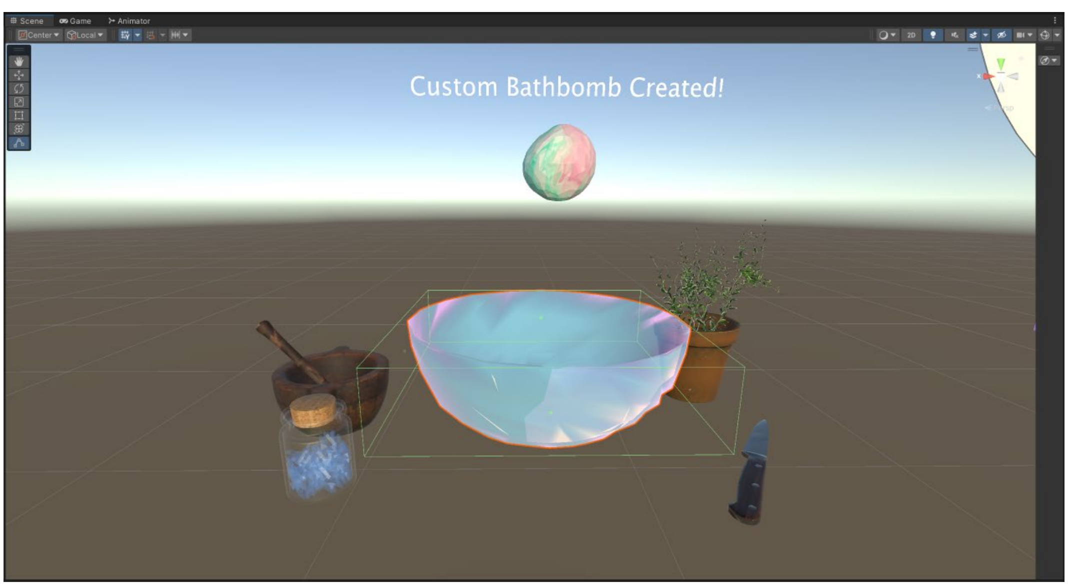


Image 26: Screenshot of Unity Engine window showing the collider bounds.

The customization requires the users to pinch and grab the ingredients with their left hand (Image 25) and then drop them one by one into the bowl. The bowl (Image 26) was given a collider as a trigger for detecting collision with the ingredients when they were dropped into the bowl. A script was also attached to the bowl that spawned a bath bomb when all three ingredients were added to the bowl.

Image 27: Screenshot shows the working of the 'pinch' hand pose for grabbing ingredients before placing them into the bowl as seen in MR.

5.3.3 Augmented Ceiling- Skylight

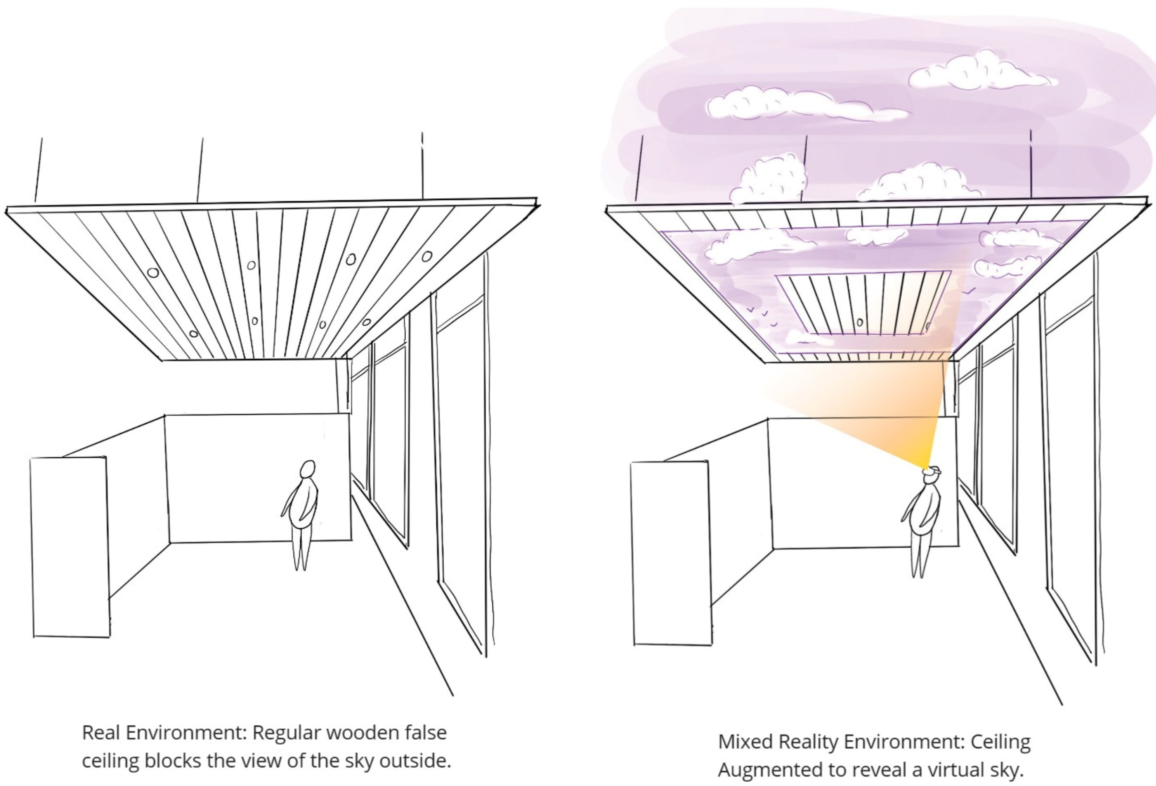


Figure 28: Perspective drawing shows (left) how the real environment's false ceiling appears and (Right) how it is virtually augmented to reveal a sky above turning the ceiling into a skylight inside MR.

The ceiling plane that is overlaid on the real ceiling was altered by breaking it into a frame with an empty space in between. A skybox with the texture of a blue sky with clouds was then masked to the ceiling plane component. This resulted in the ceiling opening up to reveal the sky; a mixed reality skylight.

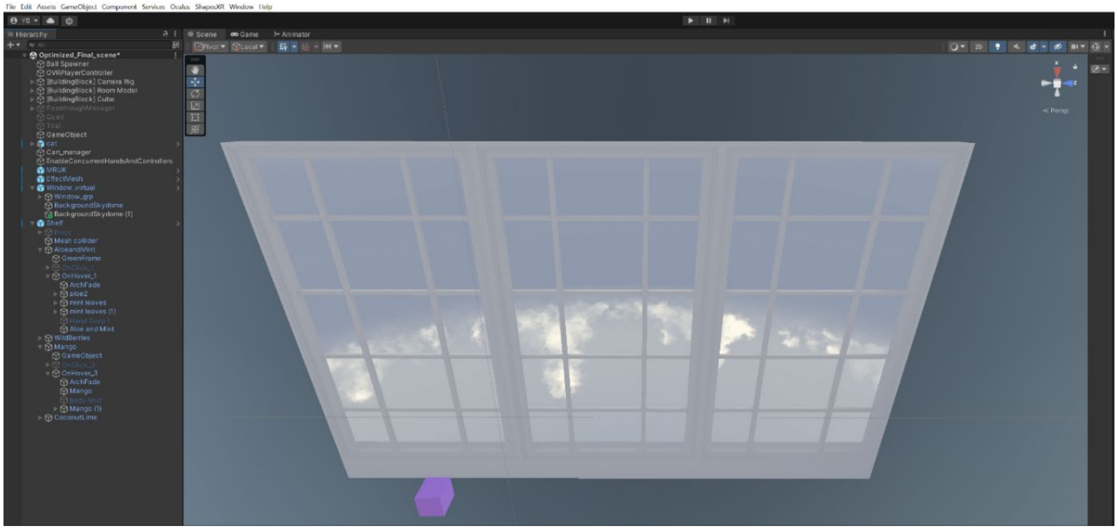


Image 28: Screenshot of Unity Engine shows the skylight in the scene.

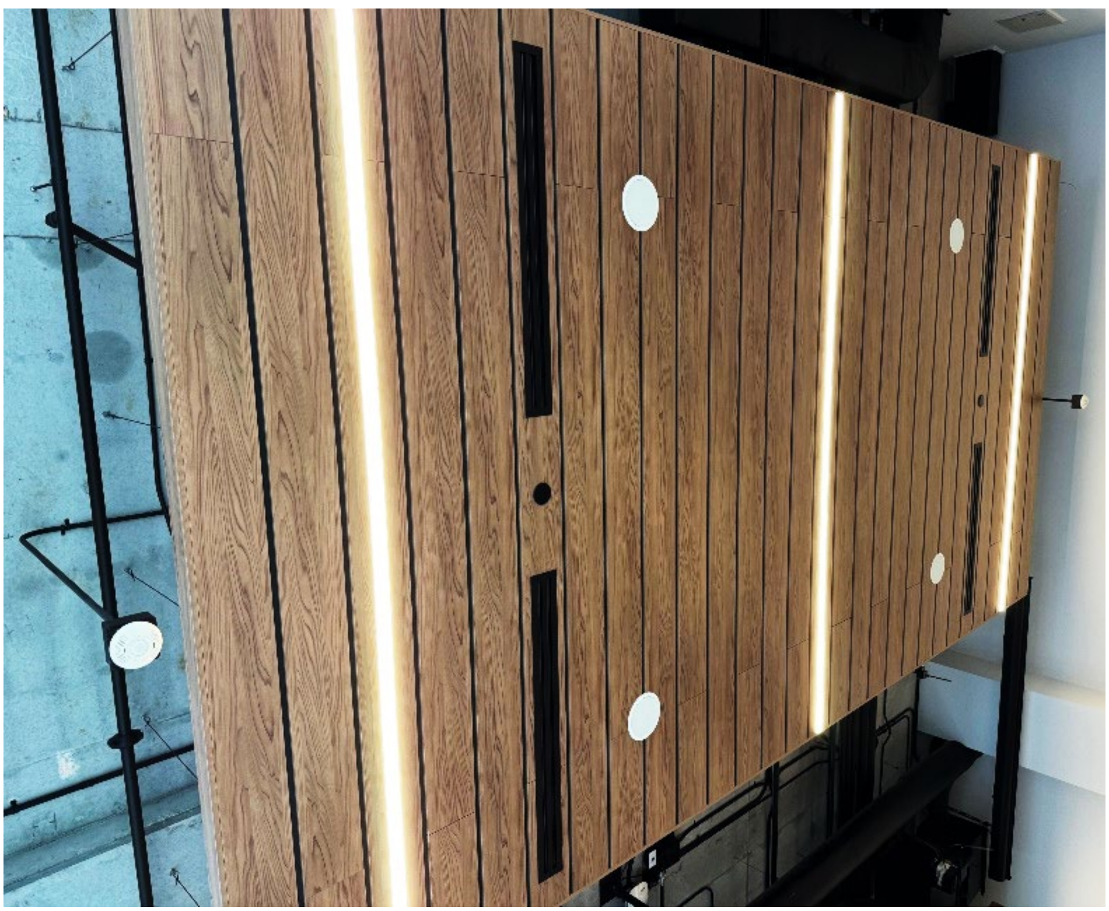


Image 29: Picture showing the real-environment ceiling.

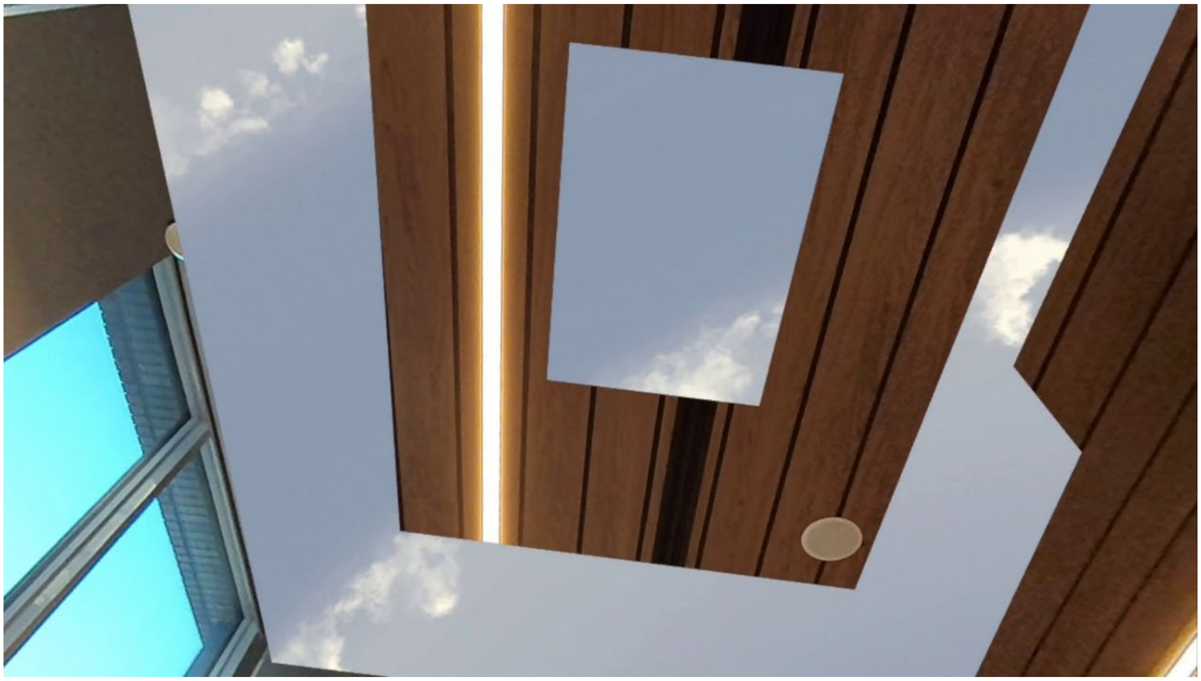


Image 30: Screenshot showing the augmented ceiling in the MR environment.

5.3.4 Wrist Cart

Figure 29: Sketch (Left) shows the position, scale, and detail of the Wrist Cart interface as it is mapped to the left hand. (Right) Also, shows how the right-hand controller, the browsing shelf, and the Wrist cart work together in an "Add to Cart" interaction.

The wrist cart was designed as a shopping cart that is tracked to the user's left hand. Similar to e-commerce websites, "add to cart" buttons were placed among the product information of the products on the shelf. When users pointed the Raycast of the right hand controller at the "add to cart" button and clicked on physical button on the controller, the product name tag would get added to the Wrist cart. Every time a user clicked on the button, the Wrist Cart on their left hand would get updated.

Some unique qualities of the cart are as follows:

- The Wrist Cart does not need to be picked up or carried around the store like a regular shopping cart in a regular retail store.

- The Wrist Cart can be upgraded to have more functionalities and perform complex tasks such as customer profile, checkout, in-store searches, and more.

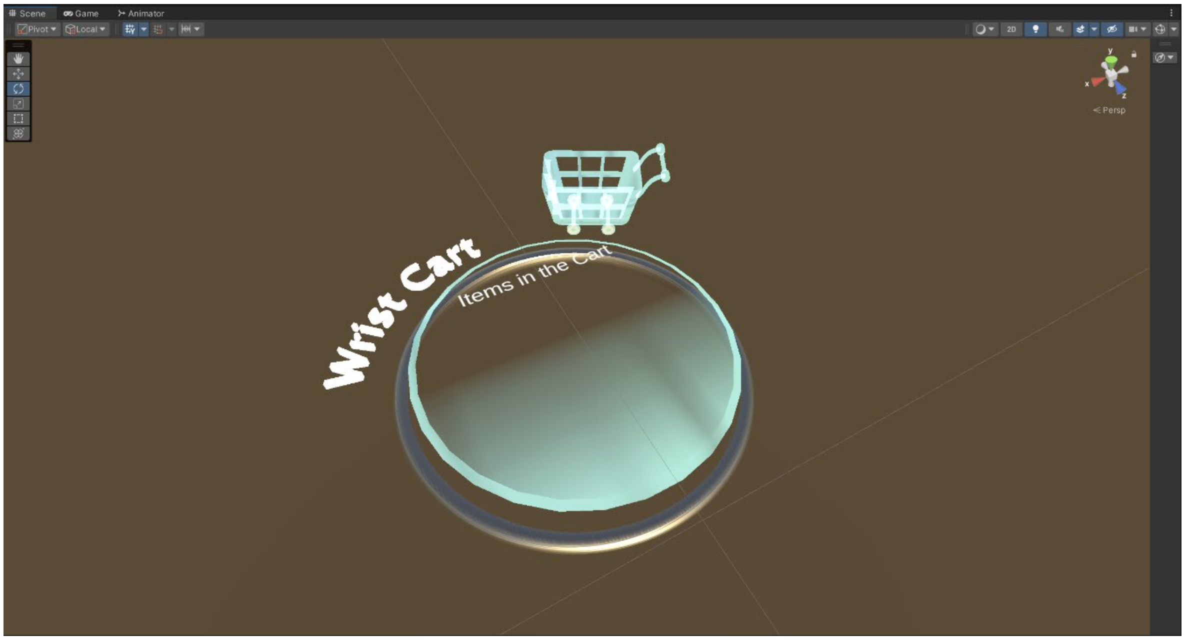


Image 31: Screenshot of the Scene in Unity Engine showing the modelled Wrist Cart.

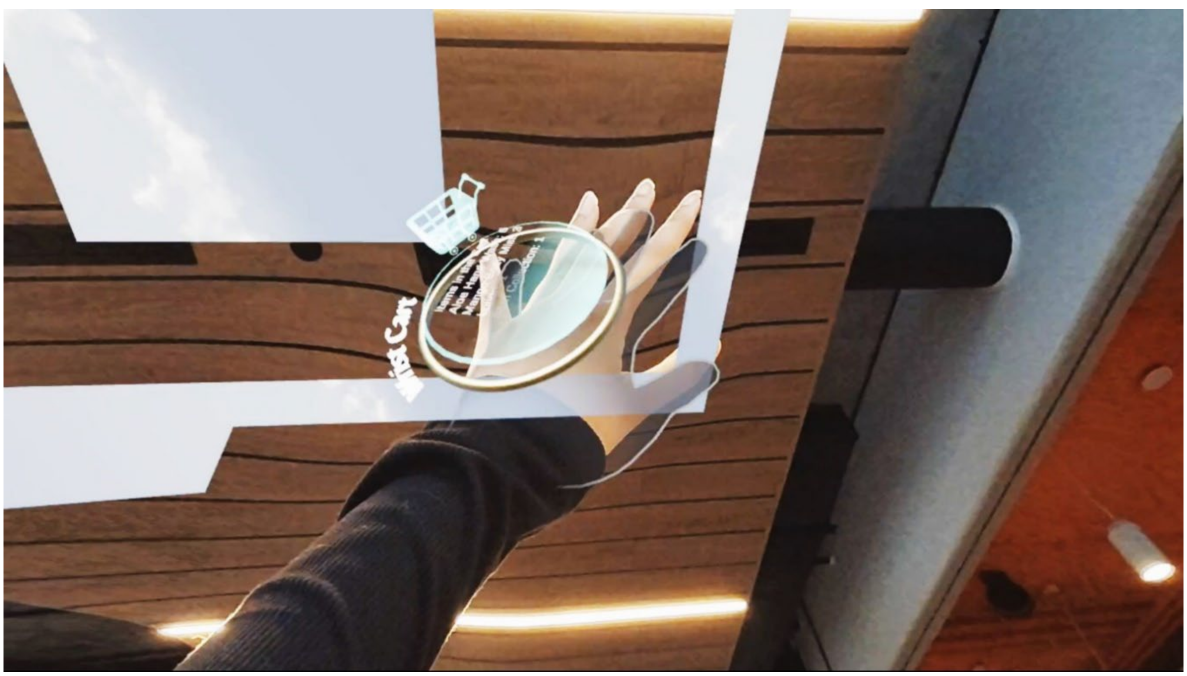


Image 32: Screenshot shows how the Wrist cart gets tracked to the user's left hand inside the MR environment.

5.3.5 Animated Presence

Different types of presence can occur in MR, such as social co-location and telepresence. The Animated presence here does not refer to the presence of an intelligent or conscious being but rather an inanimate virtual entity that is animated and blended into an MR environment.

The cat (Image 33) was placed in the room to test the effect of an animated presence on the user and observe the user's interaction.

Image 33: Screenshot showing a Cat curled up on the floor in the MR environment.

5.4 Exhibition

The exhibition was necessary for this prototype as the real and the virtual would come together in their entirety. The physical elements of the setup, such as the temporary walls, furniture, vinyl wallpapers, products, and artificial lights, were all assembled and organized on location as seen below.

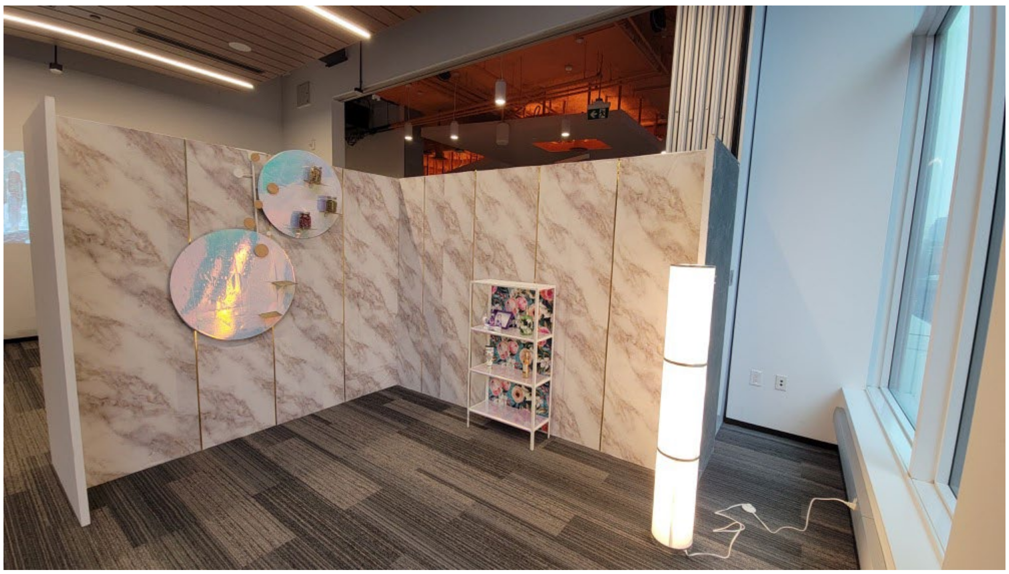


Image 34: The picture shows the final physical setup of the environment. It shows the walls, the browsing shelf, the customization/floating shelf, respective products, the ceiling, and the floor.

Image 35: Pictures showing assembly of the wall panels as designed.

Once the physical components were assembled, the room scan was setup in the Meta Quest 3. The furniture componets and the skylight was positioned to align with the real world space.

Image 36: Screenshot shows the virtual mappings on the real environment as seen in MR.

Image 37: Screenshot showing the interface layout of the browsing shelf in the MR environment.

Image 38: Screenshot showing the interface layout of the browsing shelf in the MR environment.

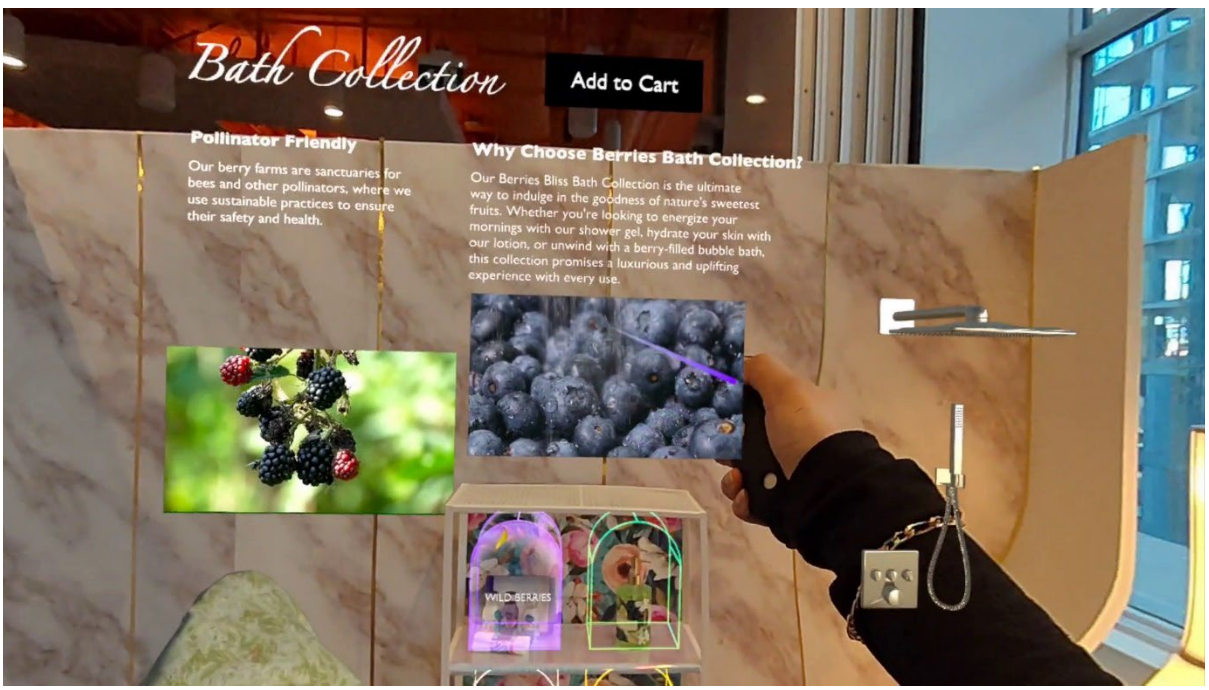


Image 39: Screenshot of interacting with the browsing shelf.

Image 40: The screenshot shows the response to the "Hover" interaction in the browsing shelf. It highlights the product and some information; in this case, the 'Aloe and Mint' handwash is highlighted.

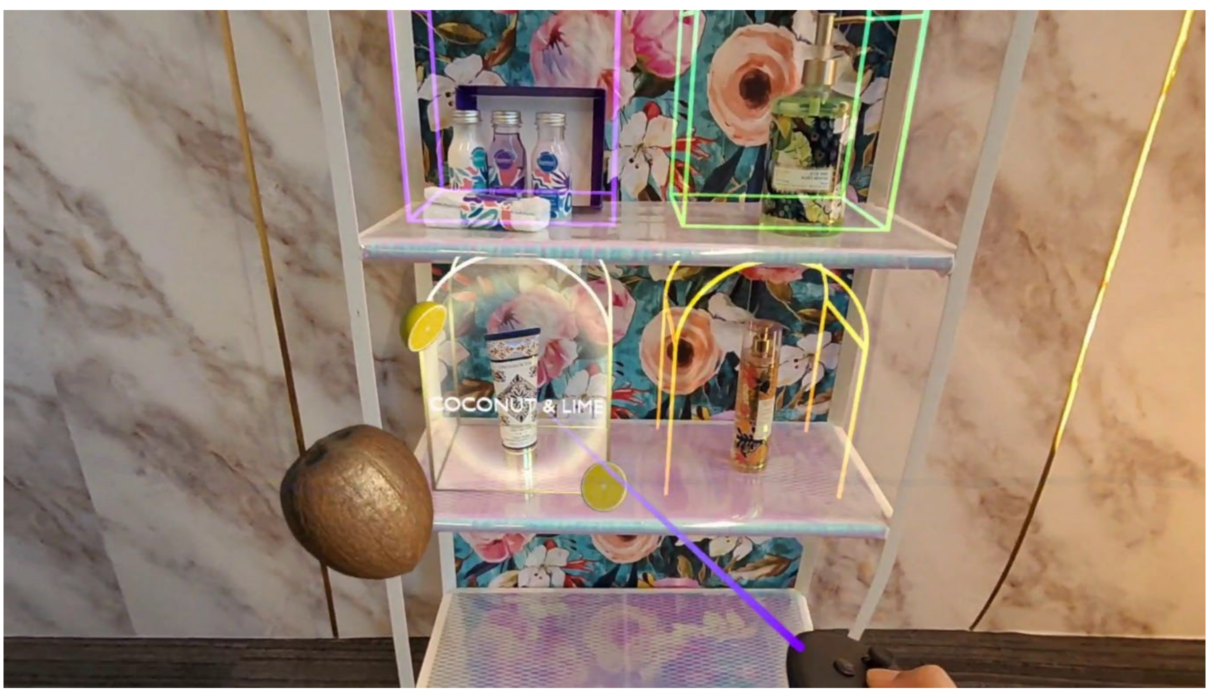


Image 41: This screenshot shows the response to the "Hover" interaction in the browsing shelf. It highlights the product and some information; in this case, the 'Coconut and Lime' Hand Lotion is highlighted.

Image 42: Screenshot of the Wrist cart tracked to the left hand as seen in the MR environment.

Image 43: Screenshot of using the Hand pose based interactions to interact with the customisation shelf in the MR environment.

Image 44: Picture of the exhibition setup from outside.

06. FINDINGS, EVALUATION AND REFLECTION

6.1 Observations from the Exhibition

The final prototype was showcased at the Digital Futures Graduate Exhibition, where it attracted a large audience. Many participants from diverse backgrounds had the opportunity to try out the MR experience, and some common observations were noted during these sessions. The findings are listed below:

- During the MR experience, most users showed more enthusiasm for the hands-free interaction as compared to the controller-based one.
- Some users attempted to pick up objects in the scene that were not designed to be interacted with. For instance, they tried to pick up small objects like fruits and baskets, which were not part of the interactive elements.

Image 45: Both Pictures show participants interacting with the final prototype at the exhibition.

- During the design process, one of the spaces demarcated was a briefing area to help users get accustomed to wearing and using the MR device. In a hypothetical MR retail store, it would be crucial to have a designated briefing area for a demo interaction, to ensure a smooth and seamless experience for all users.
- Some participants had difficulty distinguishing between the real and virtual environments. For instance, a few individuals tried placing the controller on a virtual table that wasn't present in the physical space.
- Some participants looked up at the skylight and mistook it for being real. One individual even commented that the virtual sky looked better than the real one.

Image 46: Picture of a Participant looking up at the skylight in MR.

- The MR experience highlighted the importance of designing for embodiment, which can be viewed in two ways: First- embodied interactions, such as pinch, grab, and drop and second - embodied space, where individuals use their entire bodies to engage with the virtual environment. For instance, participants would bend down to pet the

- virtual cat, look up to see the virtual sky, or even search on the floor if they dropped something.

6.2 Findings

Mixed Reality Technology, being relatively new and emerging, has limited documentation and standards for designing MR environments. As a result, the understanding of best practices for designing MR environments is still developing alongside the technology itself. This project aimed to explore the use of MR in architectural place-making by creating a context-specific MR environment. However, it was also an opportunity to develop the methods for creating such an environment. As a result, the learnings from the making process are just as valuable, if not more valuable than the final prototype, as they can be applied to various other MR environments and design scenarios in the future. Some of the key learnings from the project are listed below:

a) Real-Virtual World Alignment: It refers to aligning virtual elements with the real-world elements in an MR environment. Ensuring a consistent alignment makes for better virtual-real integration and better immersion. There are different ways to achieve this. Some of them were learned in the process and are listed below:

   - Intersecting geometry- When designing mixed reality environments, it's crucial to make sure that the virtual and real-world elements are integrated seamlessly. One of the key considerations in achieving this is to ensure that there are no unintended intersections between the real-world objects and the virtual elements. This can cause the MR environment to look disjointed and poorly integrated.
   - Light Source- It is important to ensure that the lighting in virtual elements matches that of the real-world space in blended environments. If the real-world space has a window that brings in natural light, the light source for the virtual space should replicate the position, direction, and intensity of the natural light. Similarly, if there are multiple light sources in the real world, the light rendered on virtual elements should reflect the same to maintain consistency and realism.

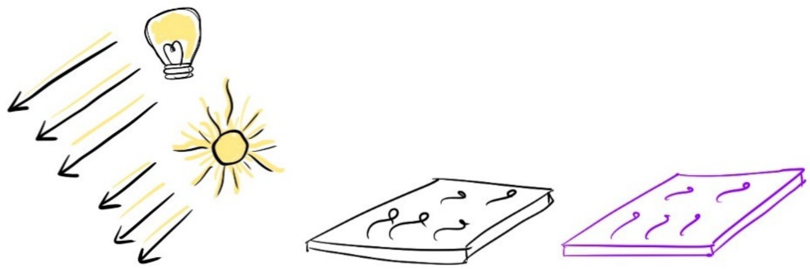


Figure 30: Illustrates light source alignment and virtual texture material copies.

- Virtual texture copies: To ensure a seamless blend between the real world and virtual environment, it is essential to create virtual texture copies of the real materials used in the physical space. This technique can help maintain aesthetic harmony in the blended environment For instance, if there is a wall in a room with marble cladding, and one wants to extend it virtually, the real material can be captured digitally and transformed into a digital texture material. This ensures that the virtual extension looks consistent with the real wall and the entire blended environment appears seamless.

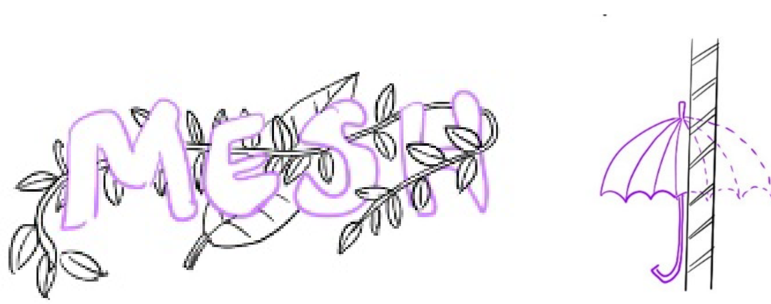


Figure 31: Illustrates Occluder material on virtual mesh geometry and an example of mapping virtual geometries within the bounds of the room.

- Occlusion: To achieve occlusion, it is essential to ensure that all furniture meshes of the real environment have an invisible Occluder material. This will help the the digital twin of the furniture that is superimposed on the furniture to obscure virtual objects in its environment, creating visual depth in the scene and improving the overall integration of the virtual and real-world elements.

- Mapping geometry- It's important to position and scale the mesh geometry correctly while mapping it to a room, making sure it doesn't extend beyond the wall, floor, and ceiling planes in the MR environment. This is because any virtual objects that extend beyond these planes won't be visible.

b) Embodied interactions: In MR environments users interact using their whole body. Even when a interaction trigger like a hand pose is only part of the body in direct interaction, there are many ways in which the rest of the body engages with an MR environment. These indirect interactions such as walking, leaning, raising an arm etc are essential to the experience as they enable the direct interactions. Hence, designing the body’s dialogue with the real-virtual environment is something to pay attention to during the making process. Below are some examples as seen in the final prototype:

- Instructions- Instructions on how to interact are important to integrate into an MR experience. When different types of interactables are mapped to different furniture or point in space in a room, instructions for interacting with them need to be delivered to the user when the user encounters the object in the space. In such cases, text-based Instructions for interaction may be placed next to the interactable object in the space. Audio or audio-visual instructions could also be played when the user encounters an interactable object.
- Proximity- The distance of the user from an interactable can be regulated by rewarding the user with visual cues. For example, the length of the Raycast can indicate to the the user the distance they need to maintain from the interactable object for triggering interactions.

c) Novel Experiences: Certain experiences cannot be created in a completely real or completely virtual space. These experiences gain their uniqueness and value because they are real-virtual, i.e., they can only be created and experienced in blended environments. Below are some example:

- Dynamic Textures Materials: Virtual texture copies can also be animated to create dynamic virtual versions of physical materials. Examples include animated copies of bricks that move virtually or Animated copies of marble that swirl slowly.
- Any building plane can be augmented, just like the ceiling plane can be manipulated to contain a skylight, real windows can be augmented to show different scenes.

6.3 Further Areas of Exploration: Different types of contexts for Context Specific Design.

While the final prototype caters to the retail store typology and related context, MR technology could similarly be used to develop other blended building typologies in future works.

The table provided below gives an in-depth explanation with examples of how various types of contexts based on architectural context classification can be addressed in MR. This table elaborates on the potential benefits of adopting a context-specific design approach in future MR environment design works. It also presents potential scenarios where different types of contexts can be utilized in MR design.

Type of Context	Architectural Design	Mixed Reality Design	MR Design Example
Geographical	This refers to the geography of a place and concerns natural features such as landmasses, vegetation, climate, rivers, etc. In architecture, geography affects the choice of materials, construction	Geography may not have a physical effect but can be referenced in design.	Weather simulation—Like the weather app on smartphones, an MR environment can change according to the real-world weather of the place, either mimicking the climate outside or responding to it. For example, If It's cold and snowy outside, it could turn on snow

	technique, built form, etc.		visuals in MR or light a virtual fireplace.
Cultural	Cultural factors in a place often influence the style and function of an architectural building. These factors include regional aesthetics, social behaviours, belief systems, and more.	The influence of culture as context in MR is largely similar to that in architecture.	Cultural presence—Similar to how we do land acknowledgments as a reminder of the history that has been systematically suppressed, MR can be used to make these histories 'present' in the Real environment on the same land.
Economic and Political	In architecture, the influence of economic and political factors is usually more discreet than direct unless it is the design of a structure like an assembly building or a marketplace.	In mixed reality, these are the driving factors of the design rather than the goal.	MR could boost a place's economy by addressing economic needs and challenges. If a place has the potential to attract tourism, MR could also help bring the place to the spotlight, 'activating it'.
Physical	Physical context refers to the physical surroundings and its elements, such as furniture, objects, other buildings, etc.	Physical context is critical in MR for context-awareness and refers to the same features of a physical surrounding as in architecture.	All the AR and MR prototypes in this research are good examples of how physical context influences MR design. Another example is public squares and building facades, which can be used as canvases.

Temporal	Buildings are designed according to different factors that constantly change such as time of day, activities, function etc.	MR itself is spatio-temporal, meaning an MR environment lasts as long as the environment is active.	The principal prototype shows how a place's Tasks and activities can be integrated into MR design. Another example: An empty office conference room can be temporarily transformed into a collaborative model-making workshop using co-presence.
User	In architecture, the users of the space define several important characteristics of the built space, such as heights, slopes, textures, function, etc	The influence of users as context in MR is largely similar to that in architecture.	In the principal prototype, the users are the customers as well as the store manager who has to setup the space. Both users would require different interfaces for their respective tasks in the same MR environment.

Figure 32: Table gives examples for potential future works that use the Context-specific design approach.

6.4 Reflection on the Research Queston:

The research asks a two-part research question, which is mentioned in chapter 1. The answers for these emerge in the form of prototypes, methods, concepts, techniques and findings. While, these can't be contained in a few lines, an attempt is made to summarize them:

Question 1: How can we use architectural elements to design mixed reality environments that are context-specific?

Response: Architecture becomes the canvas in all MR experiences. Architectural elements are the building blocks that can be virtually manipulated by creating digital twins. The characteristics of the architecture and its surrounding intangible aspects need to be recognized and then addressed in a context-specific design. An MR experience that follows a context-specific approach will reflect or respond to the context of the built environment in which it is situated.

All types of contexts inform the design. The more integrated the virtual intervention is with the real, the richer the experience. Hence, a context-specific design approach helps create not only truly blended spaces but also brings the qualities of the place forward. Here, the value of the built environment is not only retained but also compounds.

Sum is greater than parts- combining the physical and virtual worlds can enhance the overall experience and provide unique affordances that are not possible through either mediums alone. By incorporating real-world elements into mixed reality experiences, users can interact with virtual information in a more immersive and engaging way. The blend of the two gives affordances and experiential value that is unique and larger than its parts.

Question 2: How can we use architectural design methods for designing such environments?

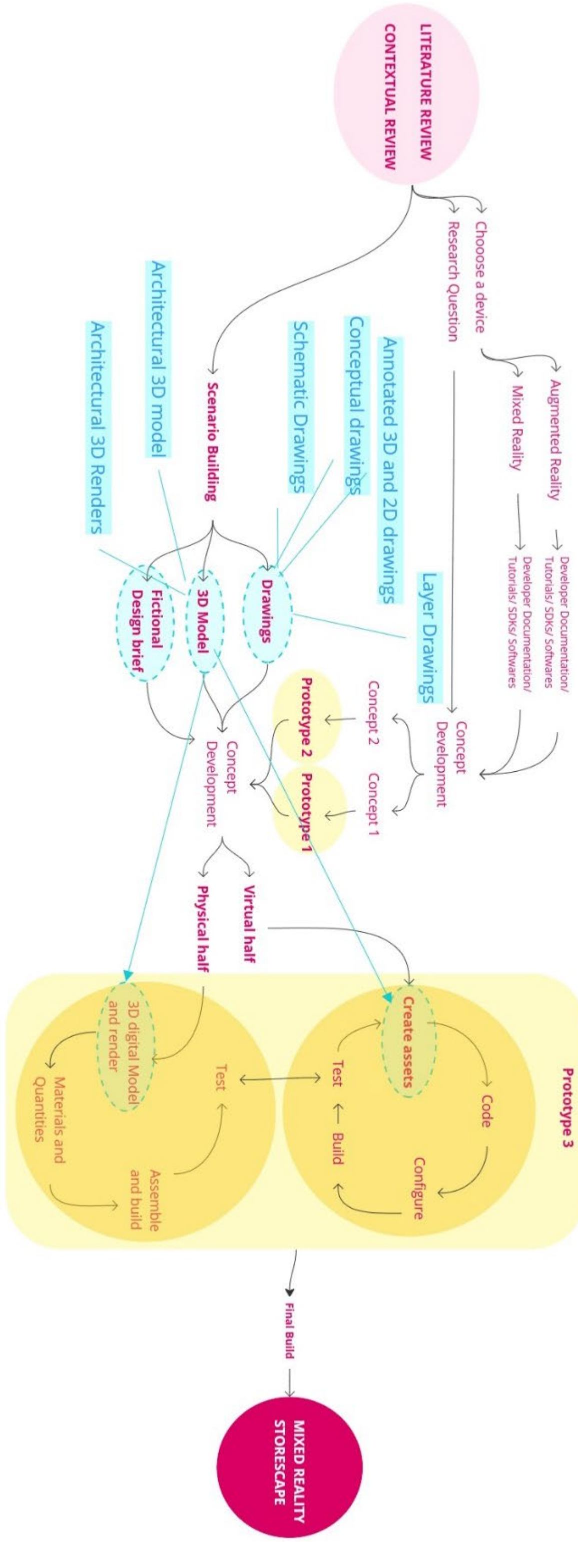


Figure 33: Illustration shows the Research workflow and also highlights the architectural methods used in the process.

In the design process (Figure 33), architectural methods were employed at various stages and served distinct purposes. Annotated 3D and 2D drawings, such as floor plans and isometric views, along with schematic drawings were crucial in bringing the ideas to life. These drawings were not just for visualization, but they also served as tools for conceptualizing the design. The 3D models played a vital role in achieving the correct proportions and scale of the exhibition space, as well as considering the integration of the virtual and physical elements in a 1:1 scale. Additionally, they provided a helpful means of contemplating how textures and materials would flow across both real and virtual environments.

07. CONCLUSION

7.1 Overview

The motivation for the project was rooted in curiosity, which emerged long before this project, from my previous architectural thesis. It made me think about the built environment as a medium for crafting experiences.

The project began with the relatively simple idea of merging two practices—two different types of space-making, two types of realities. What began as an exciting area of research, born out of curiosity and a love for science fiction, evolved into a project that has now become my creative practice.

The research examined the relationship of architecture with digital media and XR technologies. It became a thorough study of Mixed Reality technology that not only successfully identified gaps and opportunities but also created AR and MR prototypes ranging from real-virtual blended objects to context-specific real-virtual environments. The research produced methods, techniques, and frameworks that can be utilized to create more Mixed Reality Architectural experiences in the future.

The project demonstrated how XR technology could be used for much more than just visualization, to create a 'third place' that neither exists entirely in the real world nor a virtual world but a place that occurs by design when a specific part of the real world converges with its virtual half. The thesis challenges the architectural practice of place-making and shows that the practice doesn't have to be limited to crafting the physical elements of the real world; it can also extend into virtuality. It demonstrates a place-making practice of the future.

7.2 Outcome and Contribution

The project makes several novel and significant contributions to the different fields involved. Since it takes an interdisciplinary stance, spanning Architecture, HCI, and Experiential Retail, its outcomes add to these fields in different capacities.

The research intends to help shape the emerging practices of Media architecture and cybernetic architecture. It questions the standard notion of architecture but at the same time, innovates with its age-old spatial design practices for developing XR experiences.

VR technologies have often been criticized for being isolating and lacking real-world qualities. However, this project takes a different approach by utilizing MR technology to create virtual experiences that are rooted in the built environment. By doing so, it showcases how the architecture of a place can take center stage in a virtual experience instead of being hidden or neglected. Moreover, this project goes a step further by demonstrating that the value of a place can not only be retained through a context-specific design approach but the architecture of the place can also be enhanced with digital interactions and new types of immersions, which are only possible with XR technology.

The findings of this research can be a game-changer for the retail industry. With the ever-increasing popularity of e-commerce, brick-and-mortar stores are facing a stagnation and require a revolution to keep up. The potential applications of XR technology highlighted in this research can greatly expand its use in the retail sector, offering new and exciting ways to engage customers and enhance their shopping experiences. Retail stores need compelling experiences that transcend purchases and transactions, experiences that cannot be had at home on a computer screen but only by engaging one's body in an architectural space. The thesis contributes not only a new type of retail digital shopping experience but also completely reimagines a typical retail store design to propose a retail experience for the future. Through this, the research presents a new spatial typology.

The research also addresses the impact of XR technology on our society and explores potential solutions to prevent real-world locations from being replaced by virtual alternatives on web 3 or the Metaverse. It aims to find ways in which we can adapt the built environment to XR technologies while preserving its significance.

7.3 Limitations and Challenges

The research phase of the project posed several challenges, one of which was finding related work for reference. Although a few MR apps were available, they were mostly designed in a modular fashion. Additionally, the few MR projects that I came across were place-based installations or museum experiences, and there was no access to their production process. During the research period, the Meta Quest 3 was released, which was the device used to build the final prototype. It was the first standalone MR device with full colour passthrough. However, since it is an emerging technology, there is very little developer's documentation available for reference, making even troubleshooting difficult due to the lack of information available online.

As someone with a background in Architecture, I needed to learn about XR development and tools. It was a challenging journey as I had to learn various aspects of game engine development from scratch, the fundamentals of C#, and how to use Meta's SDKs to build an application for Quest 3. I spent a significant amount of time researching and learning the basics before I could start with the final development.

The final prototype had technical limitations that constrained what could be fabricated and assembled on site, resulting in a simplified physical design of the storescape. As a consequence, complex designs that required significant fabrication time, funds, and physical labor had to be eliminated.

7.4 Future Pathways

The final prototype was designed specifically for a retail store space, utilizing a context-specific MR design approach that resulted in a complete transformation of the retail experience. This design approach has the potential to be applied to other architectural spaces, including salons, museums, galleries, and more, to reimagine and transform building typologies. The retail sector offers many opportunities for exploring the design of MR retail stores. The retail typology itself can be expanded further to cater to different product ranges, interactions, types of users, and store sizes and more.

In future works, an important feature that could be included is co-presence. MR experiences in places like retail are semi-private, and adding co-presence could greatly benefit these experiences. Sharing an MR space in real-time would add the currently missing social aspect, making the experience more enjoyable and engaging.

7.5 Final Remark

The thesis presents a compelling case for Mixed Reality Architecture through prototypes, methods, and workflow, even with its limited exploration of reimagining the future retail store. It demonstrates the potential for XR technology to be used for place-making in the architecture of the future. The thesis offers a glimpse into what the built environment of the future could be like in our cybernetic future while preserving the value of the built environment as it is today.

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Appendices

Appendix A: Mixed Reality Storescape Video

The final prototype is a Mixed Reality Experience that was Exhibited at the Digital Futures Graduate Thesis Show in Toronto (2024). A screen recording of the Video is submitted along with this document. The video is a walkthrough of the experience that shows the designed MR environment and the interactions of the user.

File Name: Mixed_Reality_Storescape_Sunidhi_Naik_Thesis

File Type: MP4 / Video